

CLEAN TECHNOLOGY TRANSITION POTENTIAL IN SOUTH AFRICA'S GOLD MINING SECTOR: CASE OF HARMONY'S KUSASALETHU MINE.

By

BONGANI CHAVALALA

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UNIVERSITY OF SOUTH AFRICA**

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SUPERVISOR: PROFESSOR GODWELL NHAMO

Declaration

I, the undersigned BONGANI CHAVALALA student number 46513078 hereby declare that this thesis is my own original work, with the exception of quotations and references which are attributed to their sources. This thesis has not been previously submitted to any other university and will not be presented at any other university for similar or other degree award.

Signature.....

Date.....

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Dedication

I dedicate this work to my grandmother, Ndhlapa, Mjajiji Ngoveni (Komba hiri ntiho) you accompanied me on my first day to school, sometimes we fought for R2 pocket money that you never had. Thank you, kokwani. This work is also dedicated to my sons, Willow (my spongy), Celestial, Mxolisi and their mothers Mekateko Mashaba and Refiloe Thobejane. I pass my sincere gratitude to all people who played a role in my life in general and especially on my academic journey, Stuart Davies, Allan Poyus, Hanlie Dipernaar and Charl Mattheus. I am grateful for the different roles you played in my academic journey, career and life.

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List of Acronyms

AMIRA	Australian Minerals and Research Organization
BU	Business Unusual
BAU	Business as Usual
BACs	Bulk Air Coolers
CH₄	Methane
CC&V	Cripple Creek & Victor Gold Mining Company
CSIR	Council for Scientific and Industrial Research
CDP	Carbon Disclosure Project
CIP	Carbon-in-Pulp technology
CO₂	Carbon dioxide
CLR	Carbon Leader Reef
CP	Cleaner Production
COP15	The 15th Conference of the Parties
CMSA	Contract Mining Services Africa
CCG	Conventional Control Gear
DBSA	Development Bank of Southern Africa
DSM	Demand Side Management
ECG	Electronic Control gear
GHG	Greenhouse gas emissions
GIS	Geographical Information System technology
GEF	Grid Emission Factor
GWh	Gigawatt per hour
ICMM	International Council on Mining and Metals
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
kℓ	kiloliter
KV	Kilovolts

kPa	Kilopascal
KAuCl₄	Potassium tetrachloroaurate
MMLER	Metal Mining Liquid Effluent Regulation
MDRU-GIF	Mineral Deposit Research Unit Geophysical Inversion Facility
MT	Magneto telluric
MW	Megawatt
N₂O	Nitrous oxide
SO₂	Sulphur dioxide
SABS	South African Bureau of Standards
SMEs	Small and medium enterprises
TSF	Tailings Storage Facilities
USA	United States of America
UNEP	United Nations Environmental Program
UNIDO	United Nations Industrial Development Organization
UBC	University of British Columbia
UCG	Underground coal gasification
VIMS	Vital Information Management System
VCR	Ventersdorp Contact Reef
2D	Two Dimensional
3 D	Three Dimensional

Abstract

Countries and governments around the world have accepted the scientific argument on the prevalence and the possible effect of global warming and climate change on the environment, world economy and ultimately human life (Nhamo, 2011). Amongst all industrial corporations, the mining industry is the biggest environmental polluter due to its extractive nature and energy intensive operations. However because of its economic importance, it cannot be abandoned, instead it needs to find a win-win situation, where it continues to succeed but minimizes environmental damage.

This thesis aims to examine the possible impact of clean technology on the sustainability of South African gold mining sector. Specifically, the study aims to determine the drivers behind the move towards clean technologies and methods, identify challenges and opportunities associated with this transition at Harmony Gold's Kusasalethu mine. This was achieved through using Kusasalethu as a case study to which investigations of the effectiveness of clean technology and methods were carried out. The case study was multidimensional; exploring the effect of clean technology on energy consumption, greenhouse gas emission (GHG), water consumption, cyanide management and Kusasalethu's financial performance.

While the case study was largely qualitative it involved quantitative data analysis that had to be triangulated with other data sources and data gathering instruments to achieve legitimacy. This meant that the study had to adopt the mixed research methods. The instruments used included; key informant interviews, and document analysis, structured questionnaire and a set of open ended questions that served as interview guide. The qualitative data were analyzed by means of coding, descriptions, typologies, taxonomies and visual representations, whilst quantitative data were processed through Microsoft Excel to generate various forms of descriptive statistics.

The findings indicate that resource consumption (energy, water, cyanide) depends on the mine design and gold output rate. Clean technology implementation at Kusasalethu helped the mine reduce energy consumption and GHG emissions. However scope 2 (indirect GHG emissions associated with energy consumption) is also determined by coal production technologies and methods used by coal mines. Although data on Kusasalethu water and cyanide management and related technologies was not available, the aggregate data for all Harmony Gold mines indicated higher annual water and cyanide consumption during 2010 and 2012. In terms of Kusasalethu's financial performance and clean technology adaptation, acquisition of clean technologies increased capital expenditure temporarily. However, the

positive effects of the clean technology transition and implementation minimized operational cost and increased operational profit greatly. Although adopting clean technologies calls for increased capital expenditure, this study reveals that this expenditure pays off in lower operation costs for the mine and the environment benefits through lower GHG emission. However, clean technologies are yet to impact significantly in lowering water and cyanide consumption levels as they do with energy consumption. The study concluded that clean technology and methods played a positive role on Kusasalethu's environmental impact and financial performance by reducing energy consumption and GHG emissions. Though, more need to be done in terms of water and cyanide management.

Key words: clean technology, gold mining, greenhouse gas emissions, green economy, sustainability, sustainable development, energy efficiency, water consumption.

CHAPTER 1 BACKGROUND OF THE STUDY

1.1 Introduction

Concerns about climate change and global warming which are caused by greenhouse gas (GHG) emissions have gained momentum globally since the early 20th century. GHG emissions are produced by energy production companies, mining activities, farming, transportation systems and by the everyday activities of ordinary people (Chapple, 2008). Governments around the world face the challenge of stimulating local economic development with minimal environmental impact. To achieve this balance, cities and states are relying heavily on the ‘carrot and stick’ method. This means creating economic incentives to attract and retain business while administering green standards and regulations to offset negative environmental impact. As a long-term stimulus, many cities are also trying to build local capacity to compete in the green economy, a concept that has gained currency since the 2008 global financial meltdown.

Mining has been identified as one of the worst environmental polluters despite claims by miners that they engage in sustainable mining. Kirsch (2011) who was involved in mining activities in Sierra Leone argues that “sustainable mining” is an oxymoron. He stated that mining corporations use the term to claim ‘greenness’ that they do not have. This sentiment is shared by (Bebbington, 2011) whose argument is that mining cannot be sustainable because of the nature of its business as because mines take something out of the ground (extraction) that will be gone forever, and in the process permanently transforms the landscape. The mining sector is not only faced with environmental challenges, but social, economic as well as political challenges. An intensive analysis of sustainability in gold mining reveals that the key to sustainable mining depends on a number of complex factors such as exploration and production, economics, technology, as well as a range of legal, social and environmental constraints. Mudd (2007) argues that the history of gold mining is commonly associated with social, political, economic and environmental impacts; some of which can lead to significant negative costs.

In terms of climate change and its potential effect on economic, social and the mining sector's sustainability Nelson and Schuchard (2009) state that "mining companies often operate in some of the most politically and socially challenging parts of the world, where the industry remains an important driver of economic growth. Therefore, threats to the sector's profitability and viability, such as climate change, may have significant consequences for development in host countries. The extent to which mining avoids undermining host communities' resilience to climate change, and even fortifies that resilience, will directly impact the industry's reputation, social license to operate, and access to project financing" (Nelson and Schuchard, 2009:1)

The author notes that predictions of the future of gold mine's sustainability must take into account historical mining practices that are related to societies' where the mining takes place. These always have political and governance legislation attached. Mudd (2008) predicts that environmental costs especially in energy, water, chemicals and greenhouse cost are likely to gradually increase in the future. Given the unquestionable importance of gold mining in the world's economy and its potential negative impact in key areas of human and environmental life cycles, mining attracts some of the stringiest regulatory policies to counter environmental concerns. These environmental policies drive the mining sector to transition to clean technologies which seek to minimize environmental impact and offset any inherent production losses.

The ever tightening of environmental, social and political regulations on mining practices is a major driver for clean technology adaptation and optimization by gold mining companies. "There is a growing recognition that technological innovation can be stimulated by an environmental regulatory framework in which compliance costs are offset by production gains," (Warhurst and Bridge, 1996:911). Although financial incentives go a long way in encouraging mining companies to adopt clean technology and practices, Warhurst and Bridge argue that:

“Few regulatory policies have established incentives for industry to innovate and develop new environmental technology. Pollution prevention legislations have continued to focus on internalizing fixed environmental damage costs rather than reducing them through innovation in the production process. Technology innovation will mean a transition from remedial end-of-pipe technology, which includes dust precipitators and wastewater treatment to preventative in-pipe cleaner technology; which will reduce and even prevent waste and pollutions” (Warhurst and Bridge, 1996:11).

The technological drivers come in the form of challenges and opportunities in the gold mining sector. Adoption and implementation of clean technology are aimed at overcoming those challenges and taking advantage of the emerging opportunities associated with what Sheahan and Pollard (2013:1) call “efficiency revolution”. This means preventing pollution while maintaining financial growth within a company. Kusasalethu Mine which is owned by Harmony Gold Mines Ltd is one of South African gold mine which has headed the “efficiency revolution” call. The mine has been in the path of transitioning from energy intensive to cleaner technologies and methods in its gold production processes since 2009 (Harmony 2010). Harmony Gold Mining Company’s Sustainable Development Report (2011) indicates that the company committed to employing energy saving technologies which are in line with its energy efficiency and climate change strategy policy. The company has an estimated capital expenditure budget of R 191.4 million to implement these projects. A detailed analysis of these projects and other energy saving efforts by Harmony is the key focus of this thesis.

1.2 Problem statement

The direct (scope 1) and indirect (scope 2) GHG emissions released by mining companies are a major global problem as they are the major contributors to climate change. Harmony (2012) states that globally, South African mines fall within the top 20 of carbon dioxide (CO₂) emitters and the country is the leading emitter in Africa. Thurlow (2011) reported that in 2007, South Africa was ranked 13th in the world in terms of overall GHG emissions. The mining sector, specifically gold mines has been marked as some of the biggest energy consumers (Harmony, 2012). In South Africa, mining consumes 15% of Eskom (the power utility) annual electricity production; gold mining consumes 47% of the total electricity required by all mining activities in the country, making it by far the largest electricity user (Eskom, 2013).

Hilson (2000) observed that historically, gold mines have been using what has been termed “dirty technology.” The dirty technology often utilizes excessive amounts of energy, water and high volumes of cyanide and mercury to process gold (Hilson, 2000). The result is increased volumes of GHG emissions into the atmosphere partly from the mine site but largely from the energy provider in addition to water pollution and ecology exposure to cyanide.

Mudd (2007) observed that gold ores have been on the decline and gold price have been increasing. As a result, mining companies will employ extensive mining techniques to keep high production levels with the aim of achieving higher profits. Some of these the techniques are energy intensive and thus directly and indirectly release high levels of CO₂ into the atmosphere. The National Climate Change Response White Paper (2011) noted that in 2009, energy production accounted for 80% of South Africa’s GHG emissions. High electricity demand forces Eskom to use more coal to produce electricity to meet the increasing demands, thus emit higher levels of GHG.

Kusasaletu gold mine employs a sub-vertical shafts that use conventional mining methods to access the deeper parts of the Ventersdorp Contact Reef ore body. The mine must be experiencing higher energy and water demands and these demands should translate to increased GHG emissions, increased cyanide consumption and high operational costs. Based on the problem statement, the following objectives were set:

- I. To examine the possible impact of clean technology in the sustainability of South African gold mining sector.
- II. To assess the challenges and opportunities associated with Kusasaletu mine's transition to clean technology as informed by the green economy in the context of sustainable development.

In line with these objectives, the study raised and seeks to answer the following questions:

- I. What challenges and opportunities will the transition to clean technologies pose on Kusasaletu?

Based on the problem statement, and research question raised, the research seeks to meet the following two objectives

1.3 Research rationale

Minerals are an essential part of modern life. The search for co-existence between mines, ecology and society suggests that there be an implementation of new and cleaner mining innovations to mitigate the negative impacts of mining activities (ICMM, 2011). This research focuses on gold mines due to their economic value in South Africa economy and the environmental threats they pose. The study pays attention to the opportunities associated with transitioning to clean technology in gold mines, using Harmony's Kusasaletu Mine as a case study.

The choice of this mine is based on the fact that Harmony Gold bought Kusasalethu mine after it was declared “completely mined” by AngloGold Ashanti (Harmony 2009). Harmony Gold prospected the mine and learned that the mine still has gold reserves that could extend the mine’s lifespan by a further 18 years of mining deeper than previously thought possible. Mining deep ore bodies present energy and subsequent environmental challenges. The research seeks to determine the nature and magnitude of adopting clean and efficient technologies with a mine’s potential for causing environmental degradation in its immediate environment and contributing to climate change at large.

In view of the economic importance of gold mining to South Africa, and against the background of environmental risks that mining poses, gold mines must take proactive steps and adopt clean technologies to offset possible environmental risks. This research will contribute to the existing knowledge of the challenges and opportunities associated with transitioning to clean technology within the South Africa’s mining sector. The study will present cases of global mining companies that have transitioned to clean technologies. This will help South African gold mines benchmark their practices alongside the global mining best practices. The research will also present empirical data to various stakeholders on the challenges and drivers that the mining industry faces in transitioning to clean technology in the context of the green economy.

1.4 The study area and project profile

The Kusasaletu mine is located in the Far West Rand, 1km south-west of Carletonville in the Gauteng province of South Africa (Figure 1.1).

Figure 1.1 South Africa and Kusasaletu mine Carletonville

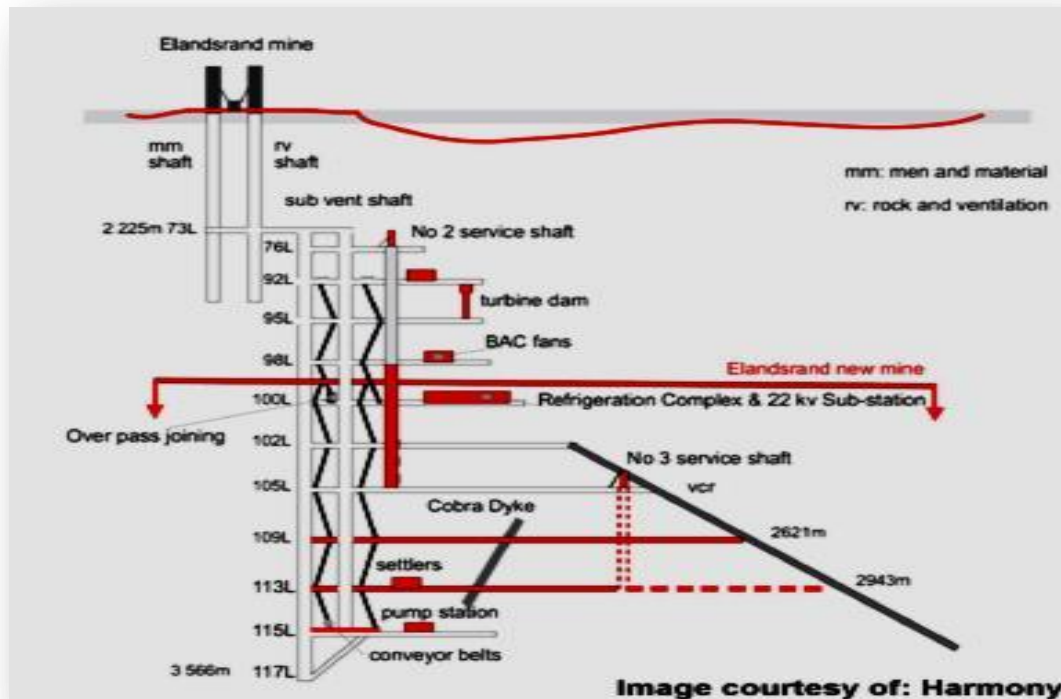


Source: Harmony (2011).

Figure 1.2 shows the mining plans of former Elandsrand mine under the Anglo Gold and the “new Elandsrand”, which is now called Kusasaletu under Harmony Gold Mine. During the period when Elandsrand was managed by Anglo Gold, production came mainly from the between 73 and 98 levels. Ore reserves on these depths were progressively mined out. Based on a feasibility study undertaken in 1990, AngloGold decided to extend the life of the mine by exploiting the western high grade Ventersdorp Contact Reef (VCR) block, below the limit of the then existing infrastructure, at depths from 3,000m to 3,500m below datum. The plan was to deepen both the sub-vertical and sub-ventilation shafts by around 500 metres and then develop the reef on four new levels – 102, 105, 109 and 113 respectively (Harmony, 2011). However, Anglo Gold’s feasibility studies indicated that such efforts did not make sustainable business sense. The studies suggested the costs related to energy, water, special

shaft design and technologies for the increased underground cooling were too high. As such, AngloGold sold the mine to Harmony Gold mines.

Figure 1.2 Former Elandsrand mine and current Kusasaletu operation



Source: Harmony (2010)

1.5 Current operational profiles of Kusasaletu shaft

Harmony acquired Elandrand Mine in February 2001, together with the adjacent Deelkraal mine from AngloGold for a cash price of R1 billion. The two mines are collectively known as New Elandsrand/Kusasaletu. Kusasaletu is being developed beneath the former Elandsrand mine. The development is intended to add a further 18 years of life to the operation. The mine produced 180,334oz of gold in 2011. Since then, production has been on the increase every year, with full production expected to reach more than 300 000oz in 2013.

After acquisition, Harmony Gold has continued with the deepening project, injecting capital investment of over R600m to mitigate Elandsrand's declining production profile. Apart from deepening the sub-shafts and developing access to the mine, a variety of other aspects had to be addressed. This included raising the reef and waste ore pass system, installing new rock hoisting facilities and integrating the two mines' ore pass systems. In addition, the work called for the construction of two settling dams, together with the provision of underground pumping stations, a refrigeration chamber, two service shafts and a turbine chamber and dam.

Kusasaletu comprises twin vertical and twin sub-vertical shaft systems. The sub-vertical shaft, which accesses the deeper parts of the VCR have been extended to a depth of 3,600 metres by the deepening project. Mining at Kusasaletu is undertaken using conventional mining methods in a sequential grid layout. The deepening project, which was completed in 2011, involved the extension of sub-vertical shafts to access the deeper parts of the VCR. Harmony predicts that this operation will result in increased energy demands from Eskom and increased water usage, thus result in higher scope 2 GHG emissions (Harmony, 2011).

Work on the project is currently focussed on accessing and opening up areas of the new mine and the development of the necessary support infrastructure. Arrangements for clear water and mud handling are also well advanced. A series of annex holes has been drilled from level 102 down to level 113, where water will enter the two 10m-diameter high flow settlers installed on top of the clear water dams between 113 and 115 levels. A new pump station on 115 levels completed in March 2011 is equipped with four seven-stage 2.4MW pumps. The pump delivers clear water from 115 levels up to existing clear water dams on 98 levels, with settled mud being pumped to the existing mud dams on 100 levels (Harmony 2012).

A decision to rehabilitate the shaft ore-pass system after major scaling took place inside these excavations resulted in only one ore-pass system being available for production. After starting with the 109/113 level ore-pass rehabilitation, estimations were that the rehabilitation work would take around four years to complete. The refrigeration complex on level 98 and

100 and installations of mini fridge plant on level 109 were completed in 2010 (Harmony 2011). Kusasalethu project started production in October 2003 and achieved full production in June 2013. The 3,000-m deep operation will have a life-span of 23 years and is expected to produce 370,000 ounces of gold per year from its estimated reserve grade of 6.46 g/mt giving it a yield of 7.95 million ounces in its lifetime (Harmony, 2011). In terms of grades, Kusasalethu is mining in an area of localized enrichment although the higher grade is diluted by waste being hoisted with reef and delivered to the plant. Ore mined at Kusasalethu is treated at the Kusasalethu plant.

1.6. Thesis outline

Chapter 2 provides a theoretical and empirical framework that has informed this study. The chapter briefly discusses the gold production cycle and then moves to deliberate on the major drivers that motivate gold mines to adopt clean and energy efficient technology and methods. Case studies from some international mines are analyzed in the context of the research topic, research question and study objectives. The chapter concludes by briefly highlighting Eskom's efforts to assist the mining, specifically gold mining to utilize energy efficient technologies and methods effectively.

Chapter three discusses the research methodology that was used to gather and analyze data based on the research objectives. This chapter also outlines ethical considerations and limitation of the study. Chapter four presents' data gathered through the methods discussed in chapter three, analyze it and draws major findings. Chapter 5 presents summary of study findings draws conclusions on all major part of the study and make suggestions on areas that need further research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to provide theoretical and empirical framework that informs this study. The chapter briefly discusses the theoretical framework of different technology implementation. This is followed by a detailed discussion of the gold production cycle, providing empirical data from some international and local gold mine's usage of different technologies in the different stages of their gold production process. The chapter then moves to deliberate on the major drivers that motivate gold mines to adopt clean and energy efficient technology and methods. The drivers are discussed in the form of risks and opportunities. The chapter concludes by providing clean technology implementation guidelines provided by Eskom.

2.2 Technology implementation approaches

Technology in the mining sector can be categorized into the three major theoretical approaches, end-of-pipe approach, Clean Production (CP), also known as in-pipe approach and industrial approach. The choice of approach is driven by factors, such as affordability of the approach, meeting regulatory measures and understanding of the long and short term implications of the approach on the environment.

2.2.1 End-of-pipe approach

United Nations Environmental Program (UNEP), 1998 defines end of pipe approach as treatment of wastes and polluting streams at the end of the production process. The technologies include a multitude of biological and chemical systems used for treating water, filtration systems, cyclones and other barrier systems used for air, acoustic enclosures.

Chavalparit (2006) note that environmental regulations expect industries to comply with state emission standards. Failure to comply can result in fines, imprisonment or closure. This approach reflects the drive by the industry to adopt a curative, end-of-pipe approach or waste

treatment strategy to control pollution. The companies have to treat their waste to meet emission standards. This expectation resulted in the installation of many end-of-pipe pollution control and waste cleanup technologies. The major disadvantage of this approach is that, although it reduces negative environmental impacts of industrial production, it however focuses on the symptoms and not on the basic causes of environmental problems. Chavalparit (2006) argues that the approach reduces the release of some pollutants, mainly to meet regulatory compliance, however fail to protect the environment because pollutants are just shifted from one environment to another.

The main advantage of end-of pipe approach as stated by Hilson (2000) and the Department National Treasury (2011) is that the approach is affordable and most advices given by commercial consultants suggest the use of add-on technologies. Besides these reasons, firms - especially Small and Medium Enterprises (SMEs) - have limited knowledge and awareness of the various possibilities for the symbiosis of ecological and economic aspects in business innovations. Consequently they mostly adopt end-of-pipe treatment systems to comply with the emission standards and reduce financial costs (Chavalparit, 2006).

2.2.2 Clean Production approach

Globally, gold mining companies have realized the need to adopt energy efficient and clean methods in their operations. This realization is driven by economic and social factors that will be discussed later in this chapter. Hilson (2000) support this claim, by stating that traditionally, mining companies used conversional end-of-pipe technology to treatment environmental pollution when it has already taken place. The end-of pipe approach is being surpassed by the more effective Clean Production (CP) approach.

Mudd (2007:118) defines CP as a “set of systems which are each designed to minimize pollution to air, land and water rather than treating pollution when it has already caused environmental predicament”. Porter and Linde (1995) define clean technology much more fully, “Economically competitive and productive technology that uses less material and/or

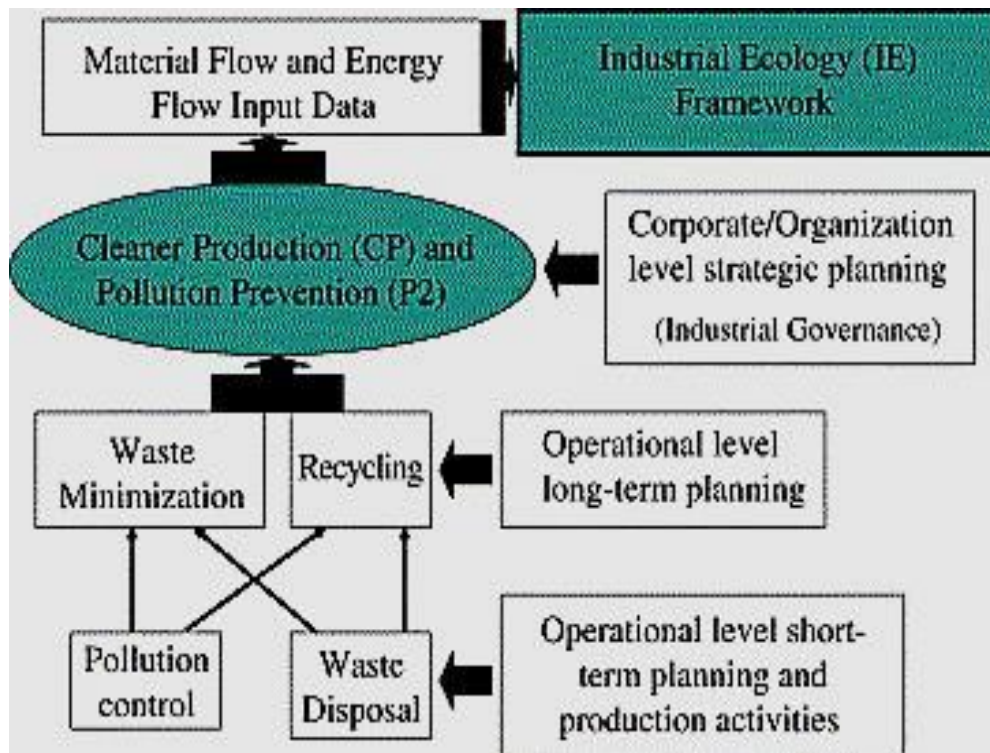
energy, generates less waste, and causes less environmental damage than the alternatives”. Thorpe (2009:28) describes the CP approach as: “a practice which eliminates the formation of hazardous substances through the use of non-hazardous chemicals in production processes, or through product or process redesign that prevents the release of hazardous substances into the environment by all routes, directly or indirectly. In general, the best way to reduce the impact of waste is to reduce the amount of waste that needs treatment or disposal”.

These measures can also result in decreasing costs of production. Although there are obvious environmental and economic benefits in implementing CP strategies, the approach can and often does entail investments. Thorpe, (2009) notes some of the advantages associated with using CP approach. These include: promote the use sources of renewable energy, thus the approach is energy efficient, reduced use of water and raw materials, re-circulates ecologically safe wastes and materials back into the production process and protects biological and social diversity. Although the CP approach is considered to be a better way to deal with pollutions and emissions, the most desirable approach is the industrial ecology approach (Shujaktk, 2011). The industrial ecology approach brings “the whole picture” into perspective and requires the mining industry to be conscious and proactive about their role in the environment.

2.2.3 Industrial ecosystem approach

End-of-pipe treatment is sometimes unavoidable and necessary to minimize the environmental burden. The CP approach aims to minimize waste streams at the source. Industrial Ecology (IE) tries to find an appropriate reuse of the remaining waste streams. The idea is to first understand how the industrial system/metabolism works and then to restructure it into a sustainable industrial ecosystem. This concept focuses on the relations among companies in a direct waste/by-product exchange (Deanna *et al.*, 1994). Figure 2.1 provides a summary of the industrial approach.

Figure 2.1 Industrial ecology methods



Source: Basu and van Zyl (2006)

The idea of IE is based on an analogy of a natural ecological system, in nature; there is little or no waste (Deanna, *et al* 1994). An ecological system operates through a web of connections in which organisms live and consume each other's products and wastes. In a similar way, every industrial activity can be interpreted as being linked to many other transactions and activities. A mine will have, and is linked to many stakeholders or actors such as raw material suppliers, customers, consumers, contractors and recyclers amongst others. Roberts (2004) stated that, although the cleaner production is already a more integrated approach than end-of-pipe solutions, it still is restricted to only one production process or one factory. In industrial ecology, an industry or set of industries, with its relations to other industries and actors, is considered as an industrial ecosystem the various actors in an industrial system can be interpreted in a way that is analogue to biological organisms.

Whereas cleaner production is process-oriented, IE is system-oriented and it covers both the long time frame and the whole array of manufacturing. According to Chavalparit (2006), the major advantage of industrial ecology is that it overcomes the shortcomings of end-of-pipe treatment and cleaner production, because it deals not only with individual firms. It strives to environmentally optimize the material flow use from the perspective of a whole industry (Eco) system. Its weaknesses are that the approach does not address issues of coordination (mechanism) within and between the separate (industrial) units. It also ignores the institutional structures in which the organizations have to operate in an environmentally sound cooperation. Table 2.1 summarizes the differences between end-of-pipe treatment, cleaner production and industrial ecology approach.

Table 2.2 The difference between end-of-pipe treatment, clean production and industrial ecology

	End-of-pipe treatment	Clean production	Industrial ecology
Target approach	Waste after Generation from Processes	Raw material, work practices And technology improvement, Final product/by-product, Production process and Service	Close loop system (Zero waste discharge)
Objective	Reduction of pollutant Emission to the environment	Reduce resource consumption and waste generation	Optimize industrial metabolism, reduce environmental impacts
Innovation	Technology only	Technology integrated with management	Technology integrated with management
Production process	Concern on emissions from processes	Concern for raw material and energy, eliminate toxic raw materials, reducing the quantity of emissions and waste before they leave the process	Concern on utilization of waste/ by-product by other industries, Waste exchange
Application Level	Single company	Single company	Community of business
Co-operative approach	Industries	Industries and commercial	Industries, commercial and residence

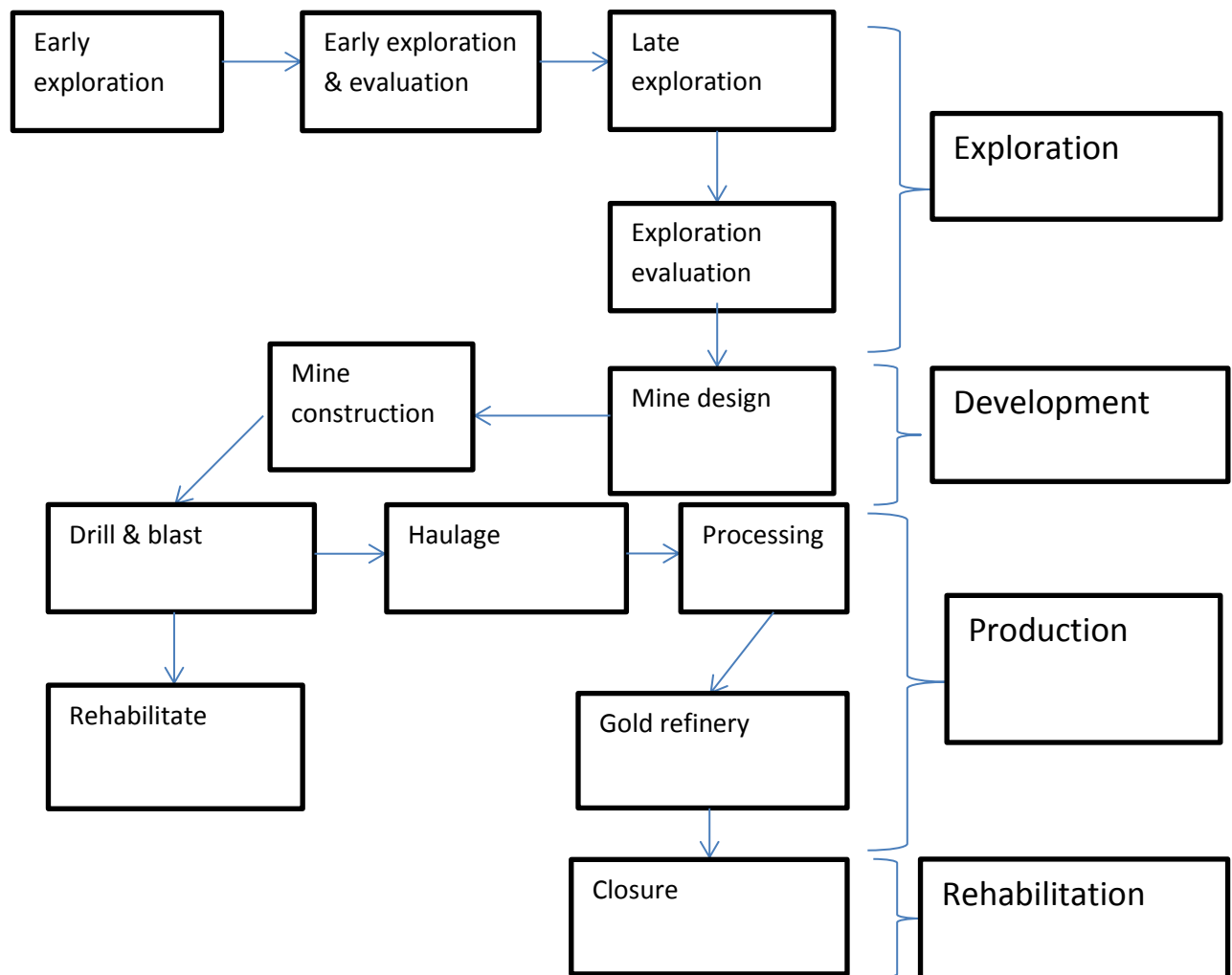
Source: Chavalparit (2006)

Gold mines employ these technology approaches throughout their gold production processes. The next section discusses the practical applications of different technologies in the gold production process. Application of these technologies falls within any of the approaches discussed.

2.3 Gold production process, technology and methods

According to Mjimba (2011) modern gold mining follow typical four stages which are; (i) exploration dealing with locating and proving a deposit, (ii) the mine development section deal with the construction of a mine to access a proven reserve (iii) the production section deals with the extraction of the minerals from the ore body and processing the ore. This includes, blasting of the ore rock and underground transportation of ore also known as haulage and (v) rehabilitation is conducted after closure to allow for further productive use of land after mining. The different stages employ technologies and methods to achieve their objectives. Figure 2.1 provides a summary of these stages.

Figure 2.2 Stages in gold mining



Source: Adapted from Mjimba, (2011).

2.3.1 Exploration

Exploration technology has assisted gold mines save time, energy consumption and operational costs. South African gold mining industry is fast becoming aware of the need to adopt clean and energy efficient technologies to mitigate high production cost, maximize production, and prevent environmental pollution and to avoid the eminent carbon tax. Mudd (2008) cites 2006 data provided by the Contract Mining Services Africa (CMSA), that shows

that in 2006 gold production in Africa reached emissions of up to 550 (Gj/kg Au) per 0.9 gold grade (g/tAu) compared to Canada which emitted 200 Gj/kg Au per G/t Au. Although gold mines generally do not emit high levels of GHG directly, their energy intensive production methods and processes place high energy demands of electricity producers who then have to develop clean energy production technology.

Mining exploration technology is highly driven by the need to improve from the two dimensional (2D) realm to three dimensional (3D) realm of data mapping and visuals. Australian Minerals and Research Organization (AMIRA), University of British Columbia (UBC) Mineral Deposit Research Unit Geophysical Inversion Facility (MDRU-GIF) and AMIRA Project 740- Predictive Mineral Discovery Cooperative Research Center (PMD*CR) have focused on petrophysical analysis of known ore systems. The petrophysical properties determine what geophysical techniques can best be used to target mineralization. Magnetotelluric (MT) data, for example, have traditionally been acquired and processed in 2D (Robert *et al.*, 2007). For solving real exploration problems, data need to be processed in 3D rather than 2D.

A majority of international and South African gold mining companies have adopted the use of the 3D technology and the Geographical Information System technology (GIS) for exploration. Goldfield in Tanzania uses ArcGIS as its main platform for exploration and uses Geosoft Target for drill hole plotting. Geosoft Target's ability to map out and locate exact ore body location for precise drilling and analysis of minerals save Goldfield time, energy and money. The main technological advantage of Geosoft is its ability to present data in 3D visuals and making data sharing between different software of different formats possible and easy. The current Geosoft 3D technology is a transition from the older ArcView which used 2D technology (Geosoft, 2010). The 3D, and Geosoft technology can be classified under clean and energy efficient technologies and methods because of their ability to locate gold ore deposits precisely, thus helping mining companies avoid "trial and error" drilling that often use energy, water and cost a lot of money.

2.3.2 Development

Mine development involves mine construction and design. South Africa is home to the deepest mines in the world. The deepest mine in the world “Mponeng” meaning look at me in Sesotho is located 10km from Carletonville, west of Johannesburg and is owned by AngloGold. The mine currently reached 4.5km depth (Bleby, 2012). To mine successfully at these depths, the mine needs to employ the most resources efficient technologies. DRDGOLD (2012) reported that the average depth of their mines is between two to four kilometers below surface. To operate in such depths, cooling systems must be optimized. GoldFields (2010) reported that around 48 per cent of electricity in the mine is used for ventilation, cooling and pumping water. The cooling requirements intensify in proportion to the deepening of the mine. The ore body is blasted and mined, the blasted remains known as ‘stopes’ or ‘faces’ are cleaned and transported to the surface. On-site blasting has led to fatal accidents in the past. In 2011, Anglo Gold Ashanti announced that it has tested non-blast technology which will replace old and dangerous blasting and explosion technology.

2.3.3 Production

Atlas Copco, a Frankfurt based mining equipment manufacturer has improved the current drilling machines. The modified versions of their drilling machines are said to be 20 to 30 percent faster than comparable versions. The advantage of the new drill is that it derives a damping system that absorbs reflex shock waves thus, saves energy that could have been wasted by shock waves. Germany's Bauer is due to present a new deep drilling rig which can drill down to 7,000 meters and will be "hands free". There are 200 to 300 competitors in deep drilling companies in Germany, but there are only two or three that have 'hands-free' technology (Sheahan and Pollard, 2013).

At present, most of SA's deep-level gold and platinum mines use handheld pneumatic drills to bore holes in the underground rock face. In pneumatic drills, compressed air drives the drill bit. Explosives are then inserted into the holes to blast the rock. The problem with pneumatic drilling is that it is very energy-and water-intensive. A compressor which compacts the air for the drill is on the surface, which can be thousands of meters above the

actual drilling site. The distance between the surface area where the compressor is based and the actual location of the drill makes this technology energy inefficient as there are often leaks in the pipes leading to the drill. As a result of these leaks, only 1% of the electricity intended for the drills is productively utilized (Business Day, 2013).

The need to develop energy efficient drills is growing and mining equipment manufacturers are intensifying their technological innovation, Sheahan and Pollard (2013) call this the “efficiency revolution”. Some South African gold mining companies such as Goldfields are already benefiting from the “efficiency revolution”. The company commissioned the newly improved, Peterstow drills. The Peterstow drill employs a patented closed-loop water hydraulic system in conjunction with modular power packs, which are taken underground. The design drastically reduces water and electricity usage. It also decreases the chance of flooding, meaning that mines do not have to install and pay for additional facilities to pump water back to the surface.

Ulrich Schoepf of the Deep Drilling division at Bauer Maschinen state that, although improvements cannot really be made on drilling as a practice, safer drillers that reduce downtime and are energy efficient will go a long way in helping a mine realize improved profits while sparing the environment (Businessday, 2013). Sheahan and Pollard (2013) describe the investment benefits that can be realized by using energy efficient drillers: “The big benefit on the mining side is that productivity and production costs is so extremely measurable, Manufacturers can say 'yes, our product is 30 percent more expensive, but since the downtime is thus much lower, your investment will still pay off” (Sheahan and Pollard 2013:1).

In addition to higher energy consumption, water consumption is also higher in underground mining than in surface mining. The consumption increases with depth. For underground cooling and ventilation, Goldfield mine is investing in the Ice Chiller project also known as hard-ice technology (Gold Fields 2010). The company has employed Ice Chillier technology

in its Kloof mine to attain cleaner, energy and water efficient underground cooling. The mine estimates that this innovation will reduce GHG emissions by six per cent (Gold Fields 2010). DRDGOLD manages water usage by using harvested water stored in a closed circuit called Tailings Storage Facilities (TSF). TFSs are a result of ore that need to be brought to the surface, crushing of ore, treatment and separation process to liberate gold from the ore body. Slurries are transported in pipelines designed to reduce power consumption. The mine invested R250 million to improve the Ergo plant's old floatation section and installed the new energy efficient fine-grid section that is estimated to increase gold production by 16%-20% (DRDGOLD, 2012). Gold Field acknowledges that water usage and management is critical in protecting the environment and managing energy consumption. In 2010, the mine used 63 million kilolitre (kℓ) of water and discharged 77 million kℓ. As a result of previous lack of rehabilitation by the previous mining company, the Cerro Corona site suffered from an Acid Mine Drainage discharge. To avoid the formation of Acid Mine Drainage in the future, Gold Field started a dewatering process called "Liquid Gold" (Gold Field, 2010).

Efficient management of water directly reduces energy consumption because energy is needed to pump water, more so in deep underground mines. Eskom (2013) state that pumps consume 14 percent of a mine's energy demand. Water for domestic use and mining processes often needs to be pumped at high pressure. Eskom suggests that the pumps should be arranged in a modular pattern of smaller and bigger pumps. This method allows each pump to run on its best efficiency zone. In 2010, Gold Fields started exploring ways to use methane as a means to generate electricity; this new technology is aimed to generate 5 MW of electricity and save around 2,000 tonnes of methane which is equivalent to 42,000 tonnes of CO₂-e. In addition to the Methane-electricity technology, four projects were identified as possible opportunities to reduce energy consumption and the subsequent GHG emissions. These projects are; (i) the installations of fuel management systems, (ii) ore haulage optimization (iii) secondary fan rationalization and (iv) exploration of solar/wind lighting technology which will replace the diesel-fired lighting at the St Ives, in Australia. Solar-powered pumps will be used in tailing dams and will replace electricity and diesel powered pumps (Gold Fields, 2010).

Haulage and transport machinery is an important aspect in the gold mining cycle. From excavation to mine closure and rehabilitation, large-scale mines utilize sophisticated haulage trucks and loaders. Cripple Creek and Victor Gold Mining Company (CC&V) which is owned by AgloGold Ashanti and based in Colorado invested in F-Series of the Caterpillar fleet of haulage trucks. The F-Series truck employ Vital Information Management System (VIMS) technology that collects and transmit machine data and turns it into useful information used to track productivity, machine performance, service scheduling, trends, diagnosis and equipment condition monitoring (Viewpoint, 2010).

Jinfeng Gold Mine in China has successfully duplicated the underground haulage technologies and methods used by Canada and Australia. This was possible because of the geographical and geological similarities of these mines. The mine uses the Cat R2900G and R1700 Load Haul Dump loaders and AD45B trucks. These latest underground haulage trucks were targeted to cover 5,500 hours in 12 months. Additional underground haulage such as overhand and underhand cut-and-fill methods supersede traditional shaft hoisting methods previously used by Chinese mines (Viewpoint, 2010). In May 2013, Sandvik, a major mining equipment manufacturer field-tested a new generation of underground hard-rock mining trucks which have an on-board jacking system that allows flat tyres to be changed quickly whenever they need to be. Automation has been at the root of many of the dramatic improvements in mining productivity in recent decades - from automated drills for deep mines to the driver-less haul trucks used in Australia's iron ore-rich Pilbara region (Sheahan and Pollard 2013).

All Haulage fleets use fuel, diesel or petrol; the machines require clean fuel that provides mechanical efficiency and maximum machine performance while leaving minimum pollution to the environment. Viewpoint (2010) states that fuel providers often provide clean fuel but contamination takes place at transportation to the mines or while mixing and being stored at the mine's storage facilities. The main contaminants are often excessive water and dirt. Dirty

fuel clog electronic fuel injectors affecting fuel economy of the haulage trucks. An uneconomical fleet of haulage trucks demands more fuel which is both economically costly and environmentally hazardous. Haulage and transportation fleets use large amounts of fossil fuels, mainly diesel and petrol. It is important that this fuel is kept and utilized efficiently.

Viewpoint (2010) recommends that fuel storage facilities are designed with a sloped tank floor that will minimize the presence of water. A suction pipe located above the tank floor level will allow only clean fuel to go through and keep water and dirt on the surface. A non-corrosive tank fitted with desiccant vent filters will remove moisture from air entering the tank. In addition to effective fuel management methods, proper selection of the haulage fleet which contains latest technology necessary for everyday gold mining is paramount. Vertical or horizontal transport systems are used to transport the ore to processing facilities by surface rail or overland conveyors. The blasted ore is broken through a process known as comminution and delivered in small particles so that the gold minerals are exposed for recovery. This process is taken in multi stages of crushing and milling circuits, screening and classification to ensure the correct size is removed from the comminution circuit.

Gold bars are transported to the metal refinery for further processing where gold reaches 99.9 purity levels. This is the level acceptable by the London Bullion Markets Association that gives buyers assurance that the gold bar is of the highest standard as stamped on the bar. Hilson (2000) states that the need to prevent and minimize environmental pollution in the gold refinement phase has led to the emergence of a number of cleaner technologies and strategies. These technologies are efficient in reducing and detoxifying wastes and pollutions released from point sources. Examples of these technologies include, but not limited to high-tech flue gas desulphurization known as acid gas scrubbers, and chemical detoxification. Gas scrubbers use lime slurries that routinely remove 90% of SO_2 from flue gases and up to 99% can be achieved by using magnesium-enhanced lime and by operating on appropriate pH and liquid-to-gas ratios. Gas scribe technology has widely been adopted by mining companies that have realized that the cost and burden of remedying soil, water and ecosystems are higher than preventing or minimizing these pollutions at the first place (Hilson, 2000).

In terms of gold processing methods, Hilson (2000) observes that, the most relevant technologies used a decade ago were known as chemical detoxification. This approach comprises of a combination of methods such as treatment of gold using hydrogen peroxide, SO₂/ air detoxification process, biological oxidation, advanced chemical recycling, catalysis and photolysis detoxification. All these processes were designed to minimize or prevent environmental damage particularly from cyanide, a chemical commonly used in gold and silver recovery from the ore-rock. After gold is removed from rock(s) cyanides remains in the pile where it becomes dangerous to the environment and species it is exposed to. However, if the chemical detoxification is applied, a mine can avoid costly chemical-induced disaster (Hilson, 2000:115).

In terms of gold recovery, Gold Field in the Zaamar, Magnolia changed from using what Byambaa and Todo (2011) call primitive gold recovery technology. These technologies include the use of sluice boxes, scrubbers and riffles. These primitive technologies pollute water and are in use by local companies in partnership with Russia and or Chinese companies. Local companies which operate in isolation tend to use much cleaner technologies such as bucket-lines, dredges with on board trommels and self-cleaning sluices. Although these are cleaner technologies compared to sluice boxes, rubbers and riffles, Byambaa and Todo (2011) recommend advanced methods such as IHC jig systems, KNELSON centrifugal concentrators, drilling rigs and washing sluices. These cleaner methods and technologies are often used by Mongolian companies which are in mining partnership with Japan, United States and Canada.

Colombia has been praised for inventing the world's first eco-gold mining methods (United Nations Environmental Program [UNEP], 2010). The new mining method was invented in Colombia in a region known as Chicó. The method was as a reaction to uncontrolled, unsustainable, and dangerous excavation and gold processing techniques, which involved the use of mercury and cyanide which led to the widespread sickness and environmental

destruction (UNEP 2010). In 2000, Oro Verde another Colombian region established the world's first certification scheme for environmentally and socially responsible gold and platinum mining. According to UNEP (2010), Oro Verde mining community uses the traditional panning techniques to separate alluvia from gold by using a plant mixture. The mining community uses the profits made to fund community development projects. The environmentally sound and socially conscious mining practices won Oro Verde the 2009 SEED Award for promoting sustainable development. In South Africa, Biomin Technologies, a subsidiary of Gold Fields Ltd has developed BIOX technology which has been available commercially for the past 15 years. Although the BIOX technology only pre-treats sulphide gold ores such as pyrite, arsenopyrite and pyrrhotite it does reduce the eventual use of cyanide and increases the rate of gold recovery during the metallurgical extraction process (Viewpoint, 2010).

South Africa is making progress on developing research on technology that can reduce and eventually replace cyanide usage. Professor Frazer of the North West University, South Africa, reported that he accidentally discovered a new technology that hopefully will replace the cyanide use in gold recovery (Infomine-africa.com, 2013). The corn starch technology is inexpensive and environmentally friendly. The new process can be used to extract gold from consumer electronic waste. The method extracts gold from crude sources and leaves behind other metals that are often found mixed together with the crude gold. Dr Liu, a lab assistant to Frazer found that alpha-cyclodextrin, a cyclic starch fragment composed of six glucose units, isolates gold best of all (Infomine-africa.com, 2013). Currently, DRDGOLD incorporated floatation modules at the end of a 50 km pipeline that links its former Crown and City deep plants to Brakpan to separate gold from sulphide. When gold and sulphide are separated, fine-grinding is performed to expose gold for cyanidation. This technological innovation and methods is estimated to increase gold recoveries and production by twenty percent (DRDGOLD 2012).

2.3.4 Rehabilitation

The last stage of the mining cycle is rehabilitation of the land. Although specifications for the technology to be used for rehabilitation and costs involved might not readily be determined in the early mining stages, provision for closure and rehabilitation is made during the mine's economic operations (Limpitlaw *et al.*, 2005). DRDGOLD state that netting, ploughing, fertilization of soil, irrigation of land and vegetation long before closure of mines is an effective and proactive way to avoid dust problems. Netting, also known as "bio wind break" involves the uses of the permeable shade net which is placed in a zigzag pattern to slow wind speed. Seeds are sown between the nets and irrigated until the plants grow. The method reduces dust levels and rehabilitates land (DRDGOLD, 2012). From exploration to rehabilitation, gold mines use different technologies. Their choices of technology and methods are governed by theoretical approaches that propose that there are drivers in a form of benefits and challenges associated with any of the approaches. The next section will discuss drivers related to a transition to clean technologies in the gold mining sector.

2.4. Drivers of gold mines towards clean technology and methods

The transition to clean technology and methods in the South African gold mining sector is driven by potential risks that threaten the financial viability of gold mining and opportunities that can mitigate high operation cost and increase operational profits. The declining ore on the higher surfaces means that gold mines must mine deeper to access the ore. In principle this results in higher operating cost as mines sink and maintain deeper shafts. In addition, legislative and regulatory policies are changing and challenging the industry to be social and environmental consciousness. This is forcing the mining industry to look for techniques and technologies that can minimize operating cost but limit environmental hazards. This entails adopting cleaner operation technologies.

Adopting clean technologies carries challenges and risks. The challenges include economic, technological, and risks include, legislative and environmental. However, adopting technology has its benefits. The benefits include the creation of new markets through innovation that creates new jobs, reducing production cost and increasing output through

energy efficient technology and methods and gaining social acceptance by visibly caring for the environment (The South African National Treasury; 2013). The challenges, risks and opportunities are discussed in the following sections.

2.4.1 Economic challenges

Economically, end-of-pipe technologies are much more attractive for mines with limited funds since initially they appear to be affordable. The South African National Treasury (2013) noted that the long term return period of clean technology investment discourages business from making upfront investments. End-of-pipe technology requires less capital investment, less development and maintenance than cleaner technologies and strategies. Hilson (2000) revealed that due to economic pressures, some gold mines are forced to abandon the more effective and the cleanest cyanide management methods (bio-detoxification) and adopt less expensive chemical detoxification methods instead. The latter methods are less friendly to the environment compared to the former.

The problem is not that there are no enough cleaner technologies in the market. Instead, the challenge is that cleaner technologies are not affordable for mining companies, especially for small- scale mines. For example, Hilson (2000) stated Noranda Incorporated., a Canadian forestry and mining company based in Toronto has the world's most advanced pollution prevention apparatuses. The company's waste water treatment, installed in 1998 cost the company Canadian \$ 1.1 million (CAN\$1. 1 million) and an additional CAN\$ 1.5 million per year to operate. Such costs are often beyond the reach of small-scale mining companies. Small scale mines often lack financial incentives from government for complying with environmentally sound technologies and practices (Hilson 2000). After studying the Tanzanian gold mining sector, Cooksey (2011) concluded:

“Mining companies in Tanzania incur a range of ‘compliance costs’ to meet international safety, environmental, accounting and CSR standards. These standards are set by international stock exchanges and industry umbrella organizations such as

the International Council on Mining and Metals (ICMM). Implementation of corporate social responsibility (CSR) programs and mitigating the environmental impact of mining activities increase the cost of gold mining significantly. A marginal mine could easily prove to be unprofitable if these costs are not managed” (Cooksey, 2011:56).

One of the biggest challenges faced by South African gold mining companies is the increasing demand for energy and the high costs of electricity. Ruffini (2013) noted that electricity alone cost South Africa’s biggest gold mining company Gold Fields, one billion Rands in 2009. This figure increased by 60% in the 2010 financial year to R1, 6 billion and is estimated to cost Gold Fields three billion Rand in 2012/2013 financial year. To mitigate these costs, Gold Fields and Harmony Gold Mining Companies have pro-actively sought to adopt and adapt to energy efficient technologies and methods to reduce energy cost and the subsequent environmental impact. Cooperation from gold mining companies through the submission of sustainable performance reports makes it possible to quantify long-term trends in gold mining and the associated environmental costs such as energy, water, greenhouse gas emission, and cyanide and soil wastes.

According to Mudd (2008), over the past decade, global gold production has reached historic levels of about 2,600 tonnes a year. This has been made possible by the combination of two factors; the rise in the real price of gold since the 1970s and the introduction of new technology for gold processing known as ‘carbon-in-pulp’. Although new technology has assisted gold mines achieve better financial stability. Trends from sustainability reports show that unit environmental cost of gold production is increasing. This means increasing energy, water, cyanide inputs and GHG emissions output. Given the long term decline in ore grades, this could mean that the environmental costs of gold production will increase substantially in tandem. With the advent of the green economy as a means to attaining sustainable development, the demand for clean gold is set to increase. Survival of the gold mining sector will depend on its ability to adapt and remain financially viable.

2.4.2 Technology challenges

According to the International Council on Mining and Metals [ICMM] (2011), the challenge faced by mining companies is that they are situated where natural geological deposits dictate. The result is a situation where mine owners have no choice in location. This geological variation poses a challenge where processing technologies required for a mining site must meet specific geological needs. The specificity can be very significant to the extent that two gold mines located in the same vicinity may at times need to apply completely different technologies to exploit their deposits. The geological challenge faced by South African miners as noted are the increasing scarcity of gold and the increasing difficulty to access the gold ore body. Gold mines therefore need to dig deeper to get the same amount of gold they previously got but with less effort, machinery and energy. This means adaptation and implementation of resource efficient technologies and methods will be key to the mines sustainability.

2.4.3 Regulatory and legislative risks

Regulatory and legislative risks derive from possible laws and regulations that impose financial penalties for releasing undesirable pollutants above a specified measure. Hilson (1999) notes that, the first environmental legislation was passed in North America and Europe in 1970. Since then, the mining industry has improved momentarily. Toxic pollutants in air emissions have dropped dramatically globally. The methods used to monitor and control waste streams have also been upgraded significantly. This has been achieved partly by integrating cleaner technologies and cleaner processes into several polluting areas of operations. According to McCourt (1999), South Africa had the Mines and Works Act (1973) that was primarily meant to address the environmental protection measures primarily concerned with prohibiting the release of water containing “injurious matter”. Potential water pollution was the main concern of the earliest protection legislation in the country. The subsequent introduction of the White Paper on Mining and Minerals in October 2008 addressed broader constitutional rights and environmental protection related to the mining industry (Department of Minerals and Energy 2008).

The possible introduction of carbon tax in South Africa was discussed at COP17, held in Durban, South Africa in 2011. At this conference, South Africa confirmed President Jacob Zuma's 2009 Copenhagen (COP15) pledge to reduce GHG emissions by 34 % by 2020 and 42 % by 2025 (National Treasury, 2013). In his 2013 budget speech the South African minister of finance Pravin Gordhan announced that the South African government will price carbon by way of a carbon tax from 1 January 2015 at the rate of R120 per ton of CO₂ and 10 per cent will be added per annum (Gibson, 2013). Thurlow (2011) views carbon tax as a tax that is based on economic principles of negative externalities. These externalities relate to the unpaid costs or benefits generated in the production of goods and services. Businesses produce products that are generated from fossil fuels, consumers contribute to this carbon footprint by consuming these products, thus supporting business practices that pollute the environment. The proposed carbon tax in South Africa will pose financial challenges to companies that leave intense carbon footprints.

Thurlow (2011) argues that a carbon tax will pose serious economic development challenges since South Africa's economy is founded on energy intensive industry such as mining which is supported by cheap coal-generated electricity. Reducing the country's carbon footprint will need serious economic transformation. According to Thurlow (2011), risks associated with the introduction of carbon tax includes: possible job losses, further energy price increases which may have negative effects on business competitiveness and possible decline in export earnings.

To balance these possible negative impacts, Gibson (2013) suggests that a tax-free exemption threshold of 60% be set, with additional allowances for emissions intensive and trade-exposed industries. In addition, government must continue to finance green concepts such as solar water geysers, procuring renewable energy, low carbon public transport, cleaning up derelict mines, addressing acid mine drainage, and supporting the countries' national parks through the green fund budget. The Department of National Treasury (2013) argues that the

country's economic growth will not be affected negatively as a broad based carbon tax will make a significant contribution towards emission reduction with limited negative macroeconomic impacts as a result of reduction of other taxes. To further offset the possible negative impacts of carbon taxes, job-retraining projects will be carried out and more investments directed towards cleaner and energy efficient technologies must be made. This will help South Africa's transition to low-carbon development without major economic setbacks and job losses (Odendaal, 2011). At the time of this research, indications were that the proposed Carbon Tax Policy was to be finalized before December 2013.

Hilson (2000) states that the challenge faced by mining companies is that environmental legislation that recognizes effective pollution prevention are amended so often that it becomes costly for mines seeking to keep up with compliance standards, as they have to keep purchasing and updating their technology and practices. An example of unstable environmental legislation in the mining sector is the Canada's Metal Mining Liquid Effluent Regulation (MMLER) which was passed in 1977 under the Fisheries Act (Hilson, 2000). According to Hilson (2000), most mines finally adjusted and achieved 98% compliance on the legislation in 1994, having struggled to adhere to the Act since it was passed in 1977. In 2002, the MMLER standards were amended, which meant that the then cleaner technologies were deemed out-dated and non-compliant (Mining Watch Canada, 2012).

2.4.5 Environmental risks

The scientific discourse on climate change which brought about the green economy concept and its underlying policies brought public concern from the late 1980s (Wingart *et al.*, 2000). Nhamo (2011) notes that the debate on whether climate change was happening or not and its effect on the environment was laid to rest by the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report published in 2007. The IPCC affirmed that the scientific basis for global warming, resulting in climate change was indisputable. The possible effects of climate change on mining, specifically on water and energy sources are described by Nelson and Schuchard (2009) who noted that Due to the wide geographic distribution of mining operations, climate change, will have complex impacts on the sector. Climactic

conditions will affect the stability and effectiveness of infrastructure and equipment, environmental protection and site closure practices, and the availability of transportation routes. Climate change may also impact the stability and cost of water and energy supplies.

Global warming and climate change are a major concern since they threaten human development and perhaps human existence. Global warming refers to “an increase in average global temperatures which is caused by natural events and human activities. Human contribution includes increases of greenhouse gas emission such as CO₂ in the atmosphere” Shah (2012:1). A thorny question is: which countries are most responsible for the effects of global warming and climate change and which economic activities contribute the most? Data from the Urban Earth (2012) shows that industrialized nations such as the United States of America (USA) emit most of the GHG. In 2009, the USA emitted 5,800 tCO₂. The New York Times (2007) reported that in 2006 China produced 6,200 tCO₂, over-taking the USA as the lead carbon emitter.

High electricity demand forces power utilities like Eskom to use more coal to produce electricity to meet the increasing demands, thus emit higher levels of GHG. Therefore, any technology that aims to reduce energy consumption in the gold mining has the potential to reduce GHG emissions and thus drives the sustainability agenda forward. However, Mudd (2008) notes that although most of the electricity used by gold mines in Africa is generated from fossil fuels, the total emissions produced in 2008 were only about 21 (tCO₂/kg Au) per 0.9 (g/t Au) compared with Australia which reaching 49 (tCO₂/kg Au) per 0.1 (g/t Au). Canada was the least greenhouse gas emitter, emitting only 8 (tCO₂/kg Au) per 29 (g/t Au).

These emission figures show that there is a close link between Canada’s investment in clean technology and its low impact on environmental pollution. According to Hilson (2000) in 1996, Canadian mines invested CANS\$116. 6 million in waste treatment facilities. In 1995, Canada’s mining industry was said to be the biggest investor in environmental protection and pollution prevention (Hilson 2000). Other countries, such as the US and Australia have since

followed Canada's example of investing in similar technologies, strategies and environmental protection.

Urban Earth (2012) noted that in 2009, South Africa contributed 511 million CO₂e at global scale. An estimated 85% of these emissions were due to energy production; electricity production contributed 45% of GHG emissions. The belief that developing countries like South Africa will be the ones hardest hit by climate change is supported by latest scientific reports expressed at the Mining Legotla, hosted by the South African (Department of Water and Environmental Affairs 2011). The report shows that although South Africa contributes 1.49% of the global GHG emissions, the country will experience extreme weather patterns characterized by increased and severe frequencies of drought, tornados and floods and other natural disasters (Department of Water and Environmental Affairs, 2011). These changes present serious environmental, economic, social and political opportunities and challenges, especially so in the mining sector.

Nhamo (2011) argues that efforts to reduce GHG emissions have to be through climate mitigation which should be done in line with the scientific confirmation that there is increased concentration of GHG in the atmosphere. These sentiments concur with those expressed by the Ministry of Water and Environmental Affairs (2011) on the National Climate Change Response White Paper which identified adaptation and mitigation as viable ways to reduce GHG emissions, improve sustainability and aid transition towards a green economy. This is important given that South Africa's economy is classified as an energy intensive economy (Ministry of Water and Environmental Affairs 2011). The ICMM (2011) notes that industry; governments, civil society organization and the general public have taken great interest in the mining sector largely focusing on ensuring that mines make a positive contribution to the society's economy and the environment over a long term. These expectations present a challenge for mines. However, they also present an opportunity to move towards sustainable development models and green economy principles.

The Brundtland report (1987:6) defines sustainable development as defined by the as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. The sustainable development concept has been used by governments, business and civil society to address issues relating to the economic growth, social equity and the environmental wellbeing. Nhamo (2011) notes that sustainable development models have been compared to the green economy concept, with commentators searching for answers as to whether the green economy concept was a contesting new paradigm or part of sustainable development. The conclusion reached from Rio+20 conference confirmed the green economy as a means to attaining sustainable development and poverty eradication (Nhamo 2011).

Chapple (2008:1) defines green economy as “clean energy economy, consisting primarily of four sectors: renewable energy (e.g. Solar, wind, geothermal); green building and energy efficiency technology; energy-efficient infrastructure and transportation; and recycling and waste-to-energy”. There are no conflicting ideas between sustainable development and green economy concepts on how they seek to positively address social life, economic growth and environmental wellbeing. The two concepts are complementary and used interchangeably in different spheres of government business and social movements to address the causes and effects environmental pollution, declining economy and increasing social inequalities.

2.4.6 Opportunities

A transition to clean technologies presents a range of opportunities that the South African gold mining sector needs to take advantage of. Creamer (2012) notes that the development, acquisition and integration of new technologies may be an increasingly important determinant of a mine’s competitiveness in the context of market growth and adhering to regulatory pressures. Opportunities presented by new technologies include; innovation and competitiveness, opening up of new markets, and the creation of green jobs.

2.4.7 Innovation and competitiveness

Innovation is important in sustaining the competitiveness of mining operations. Warhurst and Bridge (1996) argue that, theoretically new methods and improved techniques should enable higher profitable extractions of lower grade and more complex ores. The authors give an example of the advance rubber technology for tires and conveyor belts have increased capacity and scale of mineral processing techniques such as grinding and column floatation another example is the improvements in the strength of carbide steel that have enabled long-wall miners to work a face of 300-1000 meters. Carbide steel increases the durability of bucket wheel excavators and make it possible for long-wall machines to penetrate harder rock.

In a green economy context, a mine's competitive advantage is highly linked to its ability to acquire and assimilate clean and energy efficient technology. Theoretically, cleaner and energy efficient technologies should be able to reduce production costs. Innovations in the mining sector may include investment in micro-electronics, process control technology and process improvement leading to energy savings and improved profit margins. Warhurst and Bridge (1996) give an example of the Homestake Mine, a U.S based mining company that was forced by high costs of production and low mineral prices to find ways to reduce production costs. Due to closure the mine slowly began filling with water. In 2004, the South Dakota Legislatures together with a team of scientists created the South Dakota Science and Technology Authority (SDSTA).

Clean technology supported by managerial capacity in the area of environmental performance can bring new markets and a new profit center for some mining companies. Warhurst and Bridge (1996) give an example of the Australian Mt Isa Mines which in 1994 had successfully developed technology marketing group. The marketing group licensed a number of products including ISAMELT, the Jameson Cell and the ISA PROCESS, which is a copper processing technology. These cleaner technologies opened new market opportunities for the Mt Isa Mines.

In 2007, the National Science Foundation (NSF) selected Homestake as the preferred site for a proposed Deep Underground Science and Engineering Laboratory, or DUSEL to help the mine access ore at deeper levels (Sanford Underground Research Facility, 2013). Declining minerals and increasing production costs are a growing problem all over the world. However, this challenge stimulates the need to transition to energy efficient technologies which opens new market opportunities for local economies.

2.4.8 Reputation

A favorable reputation can be gained by adaptation of cleaner and energy efficient technology. Turk *et al.*, (2005) defines reputation as a collective of the mine's past actions and results. "Reputation is driven by social, environmental and economic outcomes of corporate activity and the quality and structure of the relationship that exist between a company and its stakeholders (Svendsen *et al.*, and 2002:1). Turk *et al.*, (2005) state that a good reputation is important for mines seeking entry and operating licences in communities and to explore further business markets in new environments such as those demanding environmental stewardship in green economies. The scholars further argue that a good reputation creates financial gains, and can lead to improved economic performances and sustainable business.

Sustainable mining will in the future be a result of good reputation in addition to world class technical skills and equipment. A combination of these will allow a mine to be cost effective, environmentally compliant, and gain society's approval and support. Warhurst and Bridge (1996) note that credit providers and insurance companies are increasingly becoming aware that poor environmental performance can hamper productivity and profitability of the debtor company resulting in the debtor running a risk of non-financial returns and failure to repay loan(s). Warhurst and Bridge (1996), presents an example of this scenario in case of Grasberg Mine in Iran Jaya. In the 1990's an overseas private Investment Corporation decided to

withdraw \$100 million worth of risk insurance from the Grasberg mine in Iran Jaya, on the grounds of ecological damage to forest and river system (Ibid).

2.4.9 Green jobs

One important aspect of ‘clean technology’ is the impact it has on the creation of green jobs (see Nhamo *et al.*, 2011). Slaper and Krause (2009) identify two main approaches used to identify and measure green jobs or jobs created by the green concept: industry approach and occupational approach. The industry approach determines the greenness of the company based on the number of employees the firm has under the green programs. The occupational approach counts the number of employees at all types of companies with work activities that contribute to the greening of the economy. A concern raised by these two methods and seconded by Thurlow (2011) is the potential loss of jobs that could occur when companies try to meet the green standards.

Slapper and Krause (2009) found that employees need in-house green training in contrast to external certification. This finding is also shared by Odendaal (2011) who further states that in developing countries with small and emerging business, training employees could be an expensive and time consuming exercise. An alternative way to remain green could be to outsource employees who are already trained. However, this could put untrained local communities out of work. Although there are possible negative effects associated with meeting green standards in the jobs sector, the United Nations Industrial Development Organization, (2011) argues that the green industry sector has been a great source of the much needed job opportunities for the poor and marginalized. In addition it also has been a source of upgrading informal working conditions by providing skills and technologies. United Nations Environmental Program UNEP (2011) shows that over 15 million people in developing countries are involved in urban material recycling; these employment opportunities are typically created in urban and rural areas, thus reduce crime and illegal migration.

In South Africa, the Development Bank of Southern Africa (2011) indicates that the introduction of green economy and use of new technology will result in job creation in the manufacturing, installation and maintenance sector. Although the green-led industrialization will cost more financially than the coal-based industries, the former is projected to create 300,000 jobs by 2020 (Development Bank of Southern Africa 2011). An estimated 80,000 jobs of these jobs are expected be in mining and the manufacturing sector. The jobs are expected to be in construction, operations and maintenance of the new environmentally friendly infrastructure.

By taking advantage of the opportunities brought by clean technology, the gold mining industry will remain competitive in the broad mining market. The opening up of new markets through green manufactures and services inputs will incorporate the gold mining industry into the business ecosystem ensuring that it is not isolated. In principle this should result in a sustainable gold mining industry that is driven by clean technology to minimize its environmental impact and create more sustainable jobs.

2.5. South Africa's transition to clean energy

To support industrial electricity saving initiatives through clean technologies, Eskom is developing clean technology initiatives which are termed “energy” because it involves the use of different energy production technologies, i.e. solar water heating, wind energy and coal (Eskom, 2011). The solar water heating is aimed at South African households and businesses including mines. Eskom state that hot water market constitutes approximately 30% of the South African energy consumption in the domestic, commercial and industrial sectors. Solar water heating systems will produce a cumulative of 10 000 GWh of energy by the year 2013 (Eskom 2011).

In 2013 Eskom announced that the energy regulator of South Africa granted it a license to start large scale, renewable energy project, the *Sere* wind farm project in the Western Cape. The wind farm will be made up of 46 wind turbine generators .The project will include

construction of a new substation and a 132KV distribution line. At full capacity the wind farm is expected to generate up to 100MW of power for the national grid, and will curb nearly 4.7 million tons of carbon emissions over 20 years (Times Live, 2013). These technologies will be used concurrently with coal technology to safeguard adequate electricity production. Table 2.2 provides Eskom's guidelines and methods of efficient use of energy efficient technologies common in the mining sector.

Table 1.2 Eskom's recommendations of clean technology usage for the South African gold mining sector

Technology	Area of implementation	Technology function	Technology usage methods
Motors and motor systems	Driving pumps, electric motors, fan systems, compressed air systems, processing plants, ventilation fans, conveyor belts.	Electricity conversion,	Avoid rewinding motors as this cost energy. Rewind vendors must be SABS certified. Devise an electric motor management strategy.
Compressed air systems	Drilling	Controlling heavy drills, replace electric usage	Manage air leaks; compressor should not leak 5% of compressor capacity. Discourage the use of air compressors as cooling systems.
Pumps	Underground and hostels.	Pumping drinking water, Washing, underground process application	Pumps must be selected to operate close to their best efficiency zone. For multiple arrays, consider a modular arrangement with smaller and larger pumps to allow for each pump to run within its best efficiency zone.
Fans	Underground	Ventilation, extraction of flammable gases, provide fresh air underground	Where possible run multiple pumps into different columns to reduce friction loss. Install variable speed drives to reduce demand.

Lighting	Interior and exterior lighting.	Miner's residences, administration offices, security, processing and extraction facilities.	Switch off lights where they not necessary. Use the automatic controls including photo cells occupation sensors and time switches. Electronic Control gear (ECG) consumes less electricity than Conventional Control Gear (CCG). The latter need to be retrofitted.
Heat pumps and Solar heating systems	Outside walls of mine residential buildings or at ground level depending on configuration	Minimize electricity usage; reduce conventional water heating by two-thirds.	The storage tank must have a minimum operating pressure of 100 kPa. The storage tank must be rated for interior or exterior installation. All storage tank components must be SABS certified
Refrigeration	Miner's residence	Food storage at miner's residence. Air-conditioning	Minimize the temperature lift, reduce the cooling mode, regular monitoring

Source, Eskom (2012)

2.6 Conclusion

This chapter provides the theoretical and empirical data in the context of clean technology approaches and applications. The gold production process was discussed. In general, gold mines have transitioned from reactive end-of-pipe technology and the corrective kind of technology to proactive and preventive CP approach and application. However, the much desired approach is the industrial ecology approach that incorporates the CP practices and takes into account other industries and actors. The industrial ecology approach is more desirable because it encourages an integrated clean technology and methods implementation that target all mining activities. The gold mining sector is being driven into a transition towards clean and energy efficient technologies and methods by risks, challenges and opportunities that are brought by clean technology.

South Africa, through its power utility Eskom has been making progress by investing in renewable energy projects such as *Sere* wind farm, however South Africa still depend highly on coal. This means that while the country investigates renewable energy options, in the meantime it must find a way to minimize pollutions. This can be achieved by using energy efficient technologies and methods in all sectors of society, especially gold mining.

CHAPTER 3: RESEARCH METHODOLOGY AND DATA ANALYSIS

3.1 Introduction

This chapter describes the research methods and instruments that were used to gather and analyze data based on the research question and objectives. As stated in chapter one, the main objective of the study was to explore challenges and identify opportunities presented by transitioning to clean technology and methods in the global, South African and Harmony's Kusasalethu Gold mine. This was to be achieved by assessing the theoretical framework and practical implication of different technology paradigms by different international and local gold mines. The clean technology transition was analyzed in the context of green economy and sustainable development. This chapter justifies the relevance and appropriateness of the chosen research paradigms, methodologies and instruments. Issues pertaining to ethical considerations are also discussed.

3.2 Case study research

This research employed a case study approach. Within the case study the issues are: (1) to identify the major drivers of clean technology transition at Kusasalethu. (2) To identify the challenges and opportunities associated with clean technology transition at Kusasalethu. (3) To analyze the implementation barriers for cleaner production (4) evaluate environmental performance of existing technologies to identify cleaner technology options (5) draw insight from cases of clean technology best practice from international and local gold mines.

A case study is an in-depth, thick description and explanatory insights as well as analysis of bounded systems, (Meriam, 1998, 2009; Berg, 2009; Wagenaar and Babbie 2004). Yin (2008) who states that a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not evident. Wolcott (1994) sees the case study as an end

product of field-oriented research rather than a method. From Wolcott's view, a case study was employed to gain an in-depth understanding of the impact of clean technology implementation in relation to energy consumption, greenhouse gas emissions mitigation, water consumption and cyanide management at Kusasalethu. The benefit of using a case study is that "Insights gleaned from case studies can directly influence policy, practice and future research" (Meriam, 1998:19).

According to Welman and Kruger, (1999) case studies direct us towards understanding the uniqueness and idiosyncrasy of a particular case in its great depth. Jackson (2008) points out that it provides a method to study a rare phenomenon. Rule and John (2011) note the limitation of a case study approach, it explores a general problem within a limited and focused setting; but also note that it contribute to action and intervention. The case study approach is useful because of its ability to reveal critical information about a phenomenon, since it gathers enough information about a particular situation and generate knowledge we would not otherwise have access to (Meriam, 1998:33; 2009:50 and Creswell, 1998:123). In the context of this study, the methodology assisted in teasing out clean technology transition at Harmony's Kusasalethu mine, although the findings can be generalized with other gold mines sharing similar operations profile.

The choice of using a case study to investigate trends from a single event and extrapolate the findings is supported by Berg (2009) who states that a case study is an attempt to systematically investigate an event or a set of related events with the specific aim of describing and explaining the phenomenon in its context. It helps us to understand processes of events, projects and programs and to discover context characteristics that will shed light on an issue or object in a broader context.

3.3. Case selection criteria

The choice of using a gold mine as a case study amongst all mines was based on the fact that while all mining activities consume 15% of energy in South Africa, gold mines consume 47 % of this energy. This makes gold mining by far the biggest energy consumer. Kusasalethu gold mine was chosen because of its unique mine design and operational plan that is driven by the need to access deeper gold ore reserves while minimizing resource consumption.

The ability to achieve this balance requires resource efficient technologies and the implementation of cleaner methods, more so because deep mining is much more energy intensive. As such, the study was focused on technologies related to underground mining because underground technologies consume more energy and theoretically release higher emissions and pollute more water than open-cast mining. These technologies also present higher financial expenditure than in open cast mining. The other reason for focusing on underground technologies is that data concerning non-mining technologies could not be obtained from Kusasalethu, either because the mine does not have this data or it was reluctant to share this data.

The second reason for selecting Kusasalethu as a case study was that Harmony and thus Kusasalethu by association was one of the 41 mines which reported risks associated with climate change on the 2009 Carbon Disclosure Project (CDP) (Nelson and Schuchard, 2009). In this report, Harmony stated that the threats of climate change on its operation, amongst other threats, the mine listed; flooding that can interrupt production, and may necessitate additional controls to enhance water treatment capacity. Temperature fluctuations that may increase energy demand and strain the capacity of transmission and distribution facilities and can disrupt supply to operations. Energy rationing may lead to permanent decreases in production, affecting profits and commodity prices. Investors, lenders, and insurers will pressure companies to minimize carbon liabilities and develop adaptation plans, as well as to incorporate climate change risk into due diligence. Management of climate impacts will affect share price and access to capital. It is these reasons that made Kusasalethu amongst other mines an attractive case to study (Nelson and Schuchard, 2009). Through the in-depth

study of Kusasalethu mine as a case study, it was anticipated that the research could inform future gold mines that will follow similar operation strategies and advise on the potential of energy efficient and clean technologies as well as methods on mitigating and adaptation to climate change.

3.4 Research methods

This study uses qualitative research method which focuses on a case study approach. The qualitative research approach was suitable for gathering data concerning the impact of Kusasalethu mines' investment in clean technology. In qualitative research, the inquirer purposefully selects individuals and sites that can provide the necessary information related to the research questions under examination, and most can be learned hence discovering and gaining insight (Creswell, 1998, 2011; Merriam, 1998; Teddlie and Tashakkori, 2009). Qualitative research is described by Sarandakos (2005) as a diverse and complex process that involves dealing with raw data and previously analyzed data, the method often contains statistical techniques of varying degree. Landman (1988) describes qualitative research as a study of individuals in their natural setting, to see the way in which they attribute meanings in social situations. "Qualitative research is not based upon a fixed set of rigid procedures, but nevertheless the researcher does need to develop a set of strategies and tactics in order to organize, manage and evaluate information" (Landman, 1988: 77).

To get a comprehensive view of clean technology transition at Kusasalethu, the study employed mixed methods approach mainly drawn from the qualitative research approach. The rationale behind mixed research methods is best justified by Creswell (2008) who argues, "The advantage of using mixed research methods is that combination of the methods provide a better understanding of the research problem than either of the two by themselves, this means combined; they provide more evidence, which provide a more convincing argument from different perspectives" (Creswell, 2008:29). Although used minimally quantitative approach was used to gather, interpret and analyze data relating to the mine's environmental impact, and assessing its financial performance for example, measuring annual energy consumption, levels of annual GHG emissions, water consumption and evaluating the

clean technology investment in the company's capital expenditure, operational costs and operational profits (Seale, 1999).

3.5 Primary data collection: piloting

Before the main study was conducted, the data collection process employed a pilot study to test the research instruments and logistics that will be involved in the full-scale study. "The term 'pilot studies' refers to mini versions of a full-scale study (also called 'feasibility' studies), as well as the specific pre-testing of a particular research instrument such as a questionnaire or interview schedule" (Teijlingen and Hundley 200:1). Pilot study offers the researcher an opportunity to preview and correct the data collection strategies and tools before the full study (Creswell, 2008). Table 3.1 shows the number of respondents' interviewed in the pilot study, their organization and area of expertise.

Table 2.1 Classification of respondents on the pilot study

Areas of specialty	Organization	Number of persons
Clean technology assessment.	CSIR, Council for Geoscience, Eskom, Harmony engineering and electrical	5
Environmental Policy and regulations assessments.	South African Chamber of Mines, environmental management	2
Financial performance assessments.	Harmony finance management	1
		Total: 8

To maximize chances of success on the main study, the researcher piloted the research tools on different experts from the field, who were then excluded as respondents from the main study. Teijlingen and Hundley (2001) state that the advantage of conducting a pilot study is that the researcher get to test the logistics, get a sense of where the main study could fail,

whether the research instruments are proper and whether they will achieve the intended results.

The piloting exercise revealed the need to modify some aspects of the original questionnaire, most notably the terminology of some concepts. The initial questionnaire used words such as “clean technology” instead of “energy efficient technology”, “mitigating greenhouse gas emissions (GHG)” instead of “minimizing, erasing, or reducing GHG emissions”, “adaptation of clean technologies” instead of “implementation of energy efficient technologies” A senior personnel from the South African Chamber of Mines advised:

“When expecting a response from gold mining stakeholders who are not coming from the academic/theoretical background, it is important to study their organization's documents and familiarize yourself with the terminology they use to refer to the same phenomenon. If you are talking to junior staff members use direct non-technical terms so that they will be able to either assist you or refer you to the right senior personnel, otherwise people here will feel that what you are asking is not within their knowledge and you will not get the help you need”. (Excerpt from telephone discussion with a personnel from South African Chamber of Mines, 2013).

This advice worked. I used the non-scholastic terminology when introducing myself and this research project to other a possible informants. This also meant that I had to revise the terminology in the questioner and divide it into two; an open ended questionnaire for the South African gold mining stakeholders and interview guide for the Kusasaletu employees. The major change on the questionnaire devised for Kusasaletu was its length and the fact that the questionnaire required technical information that could not be answered without retrieval of technical reports. The questionnaire also had different sections that required different respondents with varying skills and knowledge thus could not be completed by one person from a specific section. As a result, the questions had to be “relaxed” and be more open for opinion(s) or estimates than specific and exact information. However it had to

maintain a degree of technical terms as this was not a problem for senior staff members at the mine. The respondents were also advised to only complete sections that they are knowledgeable in.

3.5.1 Sampling

De Vos (1998) refers to sampling as the principles and procedures used to identify, choose and gain access to relevant data sources. According to Rule and John (2011:63) and Maree (2007), it is sometimes impractical and impossible to consult everyone involved in a case. Welman and Kruger (1999) and De Vos (1998) state that, it is impractical and uneconomical to involve all the members of the population; as such, it could be time-consuming, costly, tedious and would produce massive amount of data, which would be difficult to process, analyze and interpret. Patton (2002) highlights the fact that the logic and power of purposeful sampling lie in selecting information-rich cases in the study. Yin (2011) state that purposive sampling is a method that is typical of case study methodology to select those which are difficult to reach, and be used in this study". Individuals that pose on the topic under investigation were identified and selected to contribute their experiences, knowledge and expertise in relation to the target node.

Having identified Kusasalethu as the case in this study, it was important for the next step was to decide on the actual sample size. Bryman (2008) has argued that the decision on the actual sample size is a compromise between cost, available resources and the need for precision/representativeness. Similar concerns have been echoed by Scheyvens and Storey (2003) who have provided that as a rule of thumb, 30 cases is usually the minimum for any useful statistical analysis but also note that statisticians often prefer 100 or more cases before doing any analysis. The decision on the actual sample size was not determined by cost or resource availability nor was there a need to meet the minimum number of respondents as per statistical requirement. Table 3.2 shows sampled respondents who informed the main study.

Table 3.2 Classification of respondents in the main study

Areas of specialty	Organisations	Number of persons
Clean technology assessment.	CSIR, Council for Geoscience, Eskom, Harmony engineering and electrical	15
Environmental Policy and regulations assessments.	South African Chamber of Mines, environmental management	6
GHG emissions and Financial performance assessments.	Harmony finance management,	6
		Total: 27

The major concern was to have enough representation-the sample had to include a proportional number of relevant gold mining stakeholders in the South African gold mine. The sample also needed to cover the five main areas outlined in the questionnaire as will be discussed later in this section. As such, Table 3.1 proved classification by organizations of respondents who informed the study:

3.6 Main data collection

Having conducted a pilot study and having identified key informants all research instruments and logistics were finalized to be used in the main study.

3.6.1 Document analysis

The research relied on intensive document analysis on public and Kusasaletu reports as a way of sourcing secondary data. “Public records are the official on-going records of societies’ activities. In this case, such secondary data included the company’s documents such as annual reports and progress reports, mass media such as newspaper and magazines” (Merriam 2009: 140). Documents are ready made sources of data accessible to the imaginative and resourceful researcher but they are usually not produced for research purposes; therefore they might not necessarily forthrightly serve the purpose of bringing out

the desired or relevant information but they can contain clues and insight into the topic being studied (Merriam 2009).

The research began with the collection of the secondary data from the literature on gold production processes and some of the old and current technologies in use. Subsequently the clean technology options in each category of the gold mining industry are identified. Harmony gold annual reports were retrieved from the company's website and analyzed dating back to 2001. The focus was on Kusasaletu, the object of this research. The areas of interest to the research were; (i) resource consumption, focusing on energy, water and cyanide consumption (ii) annual GHG emissions rates, (iii) production performance, focusing mainly on the annual gold output, and (v) financial performance. From this data, annual gold output was used as constant measure against which energy consumption; greenhouse gas emissions and water consumption were measured. The financial performance section provided data relating to kusasaletu's annual revenue, operating costs, operating profits and capital expenditure. Financial performance was analyzed against variables that included annual energy and water consumption but took into consideration external factors that affected the mine's financial outlook such as Rand/dollar exchange rate, the price of gold and labor costs.

Merriam (2009) notes that using documents as a source of secondary data does not mean excluding collecting data from people through interviews and on-site observations. Along with documents analysis, both informal and formal interviews were conducted. While documentary research mostly highlights coded information from books, policy documents, websites and electronic databases, the use of key informant interviews resulted in key insights and experiences of industry leaders and practitioners led to better understanding of the structure, organization and challenges of the South African gold mine industry.

3.6.2 Formal and informal Interviews

The study made use of formal interviews with Kusasalethu managers in different divisions. Interviews were conducted with environmental managers, engineers, and financial department personnel. This method of interviewing was best suited for this category of respondents because structured questions on a formal interview are the same for each interviewee. This made it possible to compare the answers from different respondents in different mine's departments. This approach also made it possible to identify consistency and patterns the provided data. Lindisfarne Press (2001) notes that "Formal interviews are based on a set of fixed list of questions to which all interviewees respond. The responses to these questions are usually limited to a set of range of response categories. These types of interviews are verbal, face-to-face delivery of a questionnaire. Because every interviewee has been asked the same questions under the same range, the result is data which can be presented in quantitative form. It can be analyzed for trends and statistical correlation" (Lindisfarne Press 2001, 9).

The positive characteristics of formal interviews in the context of this study are that the method is useful for gathering data which will later establish patterns, trends and statistics. Since the study needed to examine the effect (s) of clean technology in different aspects of gold mining the method made it possible to establish the cause-and-effect relationship between different technologies and mine's ability to curb, for example high energy consumption (Lindisfarne Press 2001). Formal interviews have limitations, fixed categories force interviewees to pigeonhole their views into the research categories. Sometimes these categories are insufficient, overlap or they are open for interpretation. Fixed responses questions also present language problems and may use words which may be interpreted differently by different respondents. As such the responses may not be entirely valid because they are the respondent's views as channelled and restricted by the researcher's interview format (Lindisfarne Press 2001).

Informal interviews with different organizations related to mining in South Africa were conducted using email and the telephone as method of communication. The interview questions were open ended (see appendices E for the interview guide). These open-ended interviews were useful in filling gaps between literature and Harmony's annual reports. Respondents included personnel from Counsel for Science Industry Research (CSIR), South African Chamber of Mines, Eskom and Council of Geosciences. Johnston and Vanderstoep (2009) state that an informal interview allows the researcher to go with the flow and create questions as the interview goes on. The advantage of informal interview is that the absence of a formalized list of questions means that the researcher is not rigid and biased towards his own theory. Informal interviews tend to yield or expose unintended discoveries. (Johnson and Vanderstoep, 2009).

3.6.3 Questionnaire

The reviewed questionnaire guided by insight gained from pilot study was used to gather data in the main study. The questionnaire was divided into four sections (see appendices D). Section A focused on clean technology assessment at Kusasaletu, to establish the kind of technology that Kusasaletu has previously used and is currently using and the effect of those technologies on energy and water consumption. Section B was aimed at assessing GHG emission by collecting data that compare emission under old mining technologies and the new technologies. Section C examined the financial performance of Kusasaletu in relation to its adoption of energy efficient technologies and the last section, section D, was aimed to gather data relating to environmental and sustainability regulatory measures that affect Kusasaletu's clean technology transition.

3.7. Data analysis

Murkherjee and Wuyts (1998:243) have observed two general trends with data analysis and note that, "sometimes you test ideas against data, and at times you get ideas from data" the scholars advise that when conducting data analysis, "it is advisable that even as you test your ideas against the data that you don't turn a blind eye to any clues, hints, that may point you

towards more interesting insights” They offer the analogy of these two approaches to analysis thus: In practice, this dual role requires different but overlapping analytical skills. Testing ideas against data is more like a court of law testing the hypothesis of not guilty according to the available evidence. Getting ideas from data is more like detective using the available evidence to unravel the real motive/explanations behind the crime, who committed it, how it was done and why.

The former employs confirmatory data analysis, using heavy artillery – probability theory and statistical inference – and its mathematical threshold is fairly high given its reliance on formulae and statistical testing; while the latter employs exploratory data analysis and is more flexible in nature, making extensive use of graphical tools to look at data. In this case, the analysis was more exploratory than confirmatory Murkherjee and Wuyts (1998). Quantitative data derived from the survey were coded as Business as usual (BAU) and Business unusual (BU). The trends emerging out of this analysis provided the basis for further exploration into the role of clean technology and methods in reduction of energy consumption, mitigation of GHG emissions, minimizing water consumption and the consequence of all these on the financial performance of Kusasaletu.

Information gathered through the questionnaires was analyzed together with information from Kusasaletu reports and information from literature review, and data collected through observation made on field visits to the mine. Triangulating this information was important to insure validity and reliability (Marshall and Rossman 1999). The authors’ state that by using a questionnaire, the researcher relies totally on the respondent’s feedback, this can pose a limitation to the validity and reliability of the study’s findings. Triangulation of data assisted in minimizing false representation of facts. Reliability of information was achieved by asking the same question in varying forms, mainly through open ended and closed-ended questions.

3.7.1. Why a triangulated approach?

Triangulation refers to the use of multiple sources of information to test and modify one's understanding (or 'theory') of a given problem or situation. In practice it involves using different methods of inquiry, different informants and different investigators to see whether the ideas and information they generate can be accounted for by the developing theory of the issue under investigation (Stewart *et al*, 1998). Because the data came from multiple sources, i.e. Harmony annual reports, literature, questionnaires and informal interviews with different organizations associated with the South African gold mining sector, it was important to analyze all data against each source (triangulate) in an attempt to establish consistency, understanding and answer the research question. The use of multiple methods was intended to eliminate bias and shortfalls of single-method approaches.

3.8 Observing ethics

The question of ethics is of vital concern in any research study. A researcher is morally and ethically bound to protect his informants and institutions he studies from harm of any sort of harm. Informants' dignity, privacy and confidentiality were observed throughout the period of conducting the study (Bloomberg and Volpe, 2008). As such, a letter requesting permission to conduct research and use Harmony Gold Mining Company as a case study for this research was submitted to the relevant company's offices. Application forms for this purpose were read and signed (see appendices A). Written permission from the company was obtained, indicating a commitment to assist the researcher as requested in the letter (see appendices B).

They were further informed that they could decline to answer any question question(s) if they were uncomfortable with the questions. The nature, goals and objectives of the study were explained and clarified to the participants before they responded to the questions. The relationship between the researcher and the participants was kept professional and it was based on honesty, trust, fairness, respect and dignity. The researcher insured that the

respondents' rights, dignity, privacy and confidentiality of participants (Leedy & Ormrod, 2001:108;Wagenaar and Babbie, 2004; Denzin & Lincoln, 2008).

This study employed various safeguards to ensure the protection and rights of participants. The participants were given the right not to disclose their identity; the researcher used codes that protect their identity. Private documents were treated and kept confidential and were referenced appropriately. Electronic, private documents were stored safely in my personal computer's protected files. Hard copies were kept safely in my personal residence. All Harmony Gold Mine Company's policies which were prescribed by the company in allowing this study to take place in the company's environment were observed. The results of this study will be used for the research purpose only as agreed with Harmony Gold Mine.

3.8.1 Limitation of the study

The limitation of this study was that in terms of energy consumption analysis, it only considered energy savings from technologies which were only concerned with underground activities and disregarded any other/non-mining energy saving technologies and practices. This is because data from "non-mining" technologies such as Kusasalethu hostels energy saving lightings and solar water heaters was not available. Data related to water consumption savings at Kusasalethu was not available and could not be shared with the researcher. This meant only data related to water consumption could be studied. Data related to cyanide consumption specifically for Kusasalethu was not available. However, Harmony Gold Mines Company reported the group's aggregate cyanide consumption. These limitations meant that only data concerning energy consumption and savings, underground mining technologies, emitted and curbed GHG emissions informed this study.

The 2012 closure of Kusasalethu due industrial action resulted in hostile attitude from mine management when the researcher requested access and specific data related to this study. This meant that observations were limited to practices at Harmony Randfontein offices where management offices are based for all Harmony mines including Kusasalethu.

3.9 Conclusion

This chapter justified the choice of using Kusasalethu a case study as an appropriate method to study the clean technology transition in the South African gold mining sector. The research design, methods and tools related to the case study research were discussed in detail. The chapter further discussed all ethical issues that were taken into consideration before and during data collection. Limitations and constraints of the study were also highlighted. Leading from this, the next chapter presents and analyses the research findings.

CHAPTER 4: DATA PRESENTATION, ANALYSIS AND FINDINGS

4.1 Introduction

Chapter 2 discussed the gold mining value chain focusing on the old and new technologies commonly used in each stage of gold production. The drivers of the gold mine's transition from old and 'dirty' technologies to new cleaner technologies and methods were presented through a number of case studies. The aim of this chapter is to present, analyze and discuss the primary and secondary data gathered as outlined in chapter 3.

This chapter will present the major drivers of clean technology transition at Kusasalethu. Under these drivers, the following performance indicators over a period of 3 years (2010-2012) will be discussed in detail: energy consumption in relation to annual gold output, GHG emissions in relation to gold output and electricity consumption, and water consumption trends in relation to gold output. It is worth noting that Kusasalethu only started reporting on these factors in 2010.

Kusasalethu's financial performance will be analyzed against energy, water, annual gold output and other (external) factors that determined the mine's financial performance. Cyanide management will also be discussed in brief given the fact that it is not directly responsible for the kind of pollutions that this study is focusing on. By discussing in detail the major drivers of clean technology transition and providing analysis of the above mentioned indicators, the study is able to determine the challenges and opportunities associated with minimizing resource consumption at Kusasalethu mine.

4.2 Clean technology transition drivers at Kusasalethu

According to Harmony's management, the three major drivers for investing in clean and energy efficient technologies are; (i) the need to reduce operational costs, (ii) complying with government environmental legislation, and (iii) creating a positive reputation for the mine. Whilst it is desirable to meet the highest standards in all the three drivers, the high costs

associated with technologies and process changes to meet the desired outcome pose a challenge. We briefly look at the three drivers and associated challenges from a Kusasaletu Mines perspective.

Energy cost contributes 10% of Kusasaletu's operational costs and this cost has been increasing annually due to annual electricity tariff increases (Harmony, 2010). A saving in electricity costs in an era of annual tariff increase has the potential to improve the financial performance of Kusasaletu, *ceteris paribus*. This saving can be achieved through adopting energy efficient technologies and processes. However, adopting energy efficient/clean technologies and process comes at a cost. Hilson (2000) and Warhust and Bridge (1996) argue that the cost of clean technology is a major challenge in firm's convincing management to investing in clean technology. South Africa is not different in that regard. A CSIR respondent noted that currently, the gold mining sector was under financial pressure which leads to reluctance in investing in clean technology. However, state incentive such as Eskom's Demand Side Management (DSM) funding has influenced Harmony to contribute financially to clean technology implementation. Respondents from Harmony referred to state incentives as a very important motivation factor for Kusasaletu to invest in clean technology, Kusasaletu senior manager stated:

“State partnership for energy efficiency implementation motivates the mine to play its role. The partnership also means less capital investment for the mine as compared to what it should pay without any partnership. I doubt we could have invested all the money we did alone without the state's contribution” (Interview excerpt, June 2013).

Harmony Gold Mining Company's sustainable development report (2011) states that the mine initiated and approved its current energy efficiency, climate change policy and strategy in June 2010 to mitigate high energy demands and to curb GHG emissions. The policy is mainly driven by South Africa's increasing electricity costs and the need to mitigate climate change impacts. To implement this policy, in 2009, Harmony appointed senior executive

team to lead the environmental function with additional appointments in the field made in 2010. The energy efficiency and climate change policy and strategy resulted in Harmony reporting energy consumption, GHG emissions, water pollution abatement and cyanide management on each of its mines. Harmony had previously only reported on annual financial performance and gold output.

The planned carbon tax has been identified as a “very important” driver to adaptation of cleaner technologies and methods that will reduce GHG emissions. By adopting clean technologies and methods, the mine will be complying with government environmental regulations and minimizing the financial impact of the impending carbon tax. If not mitigated, high emissions will translate into higher tax and operational cost for Kusasalethu. As such, it will be important to mitigate the financial impact that will be associated with high consumption of resources and the resultant emissions. Reporting on the CDP played a major role in the mine’s decision to reduce its carbon footprint, compete with other mining companies and take advantage of the reputation that comes with being seen to care about the environment. Gold Field mine, which is considered to be a leader in sustainable mining started reporting on the CDP in 2008. In 2010, Harmony was amongst 26 South African companies and 500 international companies who reported on the CDP (CDP, 2013). The sum of these drivers played a role in Kusasalethu’s decision to adopt cleaner, energy efficient technologies and methods in all stages of their value chain.

4.3 Electricity consumption and gold output

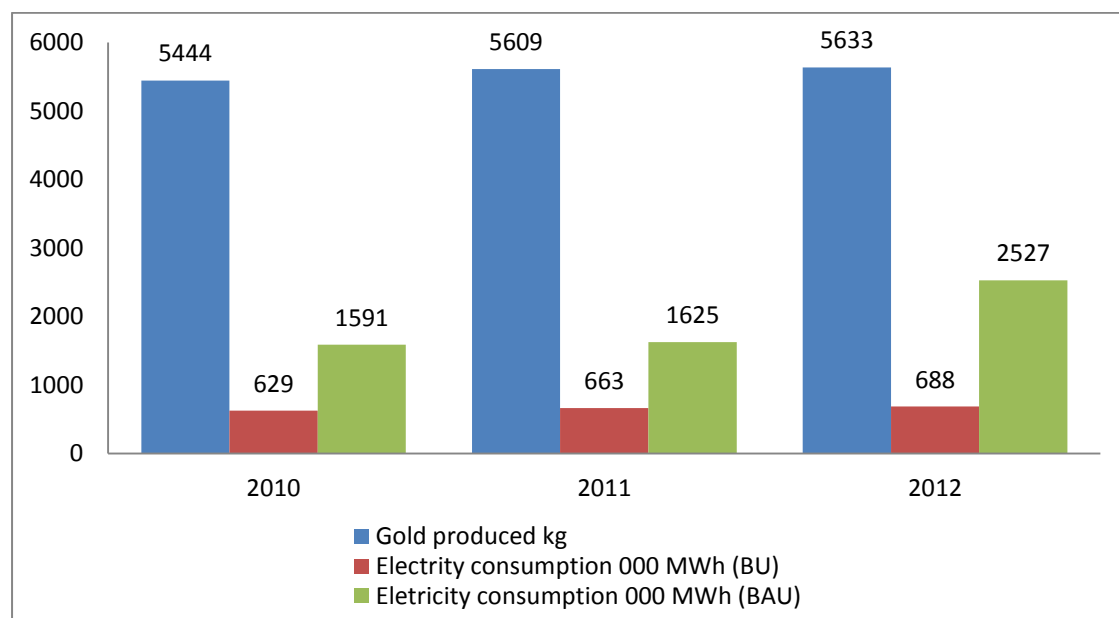
As stated in Chapter 2, the gold mining sector consumes 45% of all the electricity consumed by all mining activities (Eskom, 2013). Within Harmony, Kusasalethu mine is the highest electricity consumer. High electricity consumption is directly related to the underground technology and methods used in the mine and the annual gold output. Figure 4.1 compares the annual gold output with actual annual electricity consumption under two energy regimes; Business Unusual (BU) showing electricity consumption with the use of energy efficient technologies, and Business as Usual (BAU), a projection of what electricity consumption would have been if energy efficient initiatives were not implemented. The estimated BAU

electricity consumption is presented as the sum of actual annual energy consumed and energy saved. This assumes that energy savings were consistent from 2010 to 2012. The basis of this assumption is that the efficiency of technologies designed to last for an average of 15 to 25 years (the average mine lifespan), should be consistent particularly in their early lives. A respondent from Harmony supported this assumption stating:

“Mining technology does not change frequently because they are designed to meet mining specifications throughout a mine’s lifespan. Change in mining technology is mainly driven by regulatory pressures that identify technologies that pollute the environment and force the mining industry to change them. Other reasons for technological transition could be based on a specific technology’s ability to meet the mine’s performance demands” (Interview excerpt, June 2013).

The limitation of this method is that it only considers energy savings from technologies which are only concerned with underground activities and disregarded any other/non-mining energy saving technologies and practices.

Figure 4.1 Annual gold output ant energy consumption



Adapted from: Harmony Gold, (2010, 2011& 2012)

Figure 4.1 shows that between 2010 and 2011, annual gold output increased by 2.9 % from 5444 kg to 5609 kg and also increased by 2% from 5609 kg to 5633 between 2011 and 2012. As a result of growing gold output, in 2011 Kusasalethu contributed 14% of Harmony total annual gold output. In 2011, the major developments at Kusasalethu were extending the service shaft to 113 levels, completing the refrigeration complex at 100 levels and commissioning turbine complex at level 92. The results of these developments, was increased access to more ore (See Figure 1.2 for the levels and location of refrigeration and turbine complex). The trend of increases in gold output was accompanied by the corresponding trend of increases in electricity consumption.

Between 2010/2011, (BU) electricity consumption increased by 5.1% from 629 000MWh to 663 000MWh, this was expected given the increased annual gold output. In the 2011/2012 financial year (BU) energy consumption increased by 3.6% from 663 000MWh to 688000MWh. Energy consumption could have been higher if energy efficient technologies were not implemented. The 2010 to 2011 (BAU) projections shows that electricity consumption could have been 60 % higher (1591 000MWh and 1625 000 MWh each year respectively) and 73% higher in 2011 to 2012 (1625 000MWh to 2527 000MWh each year respectively). The marginal increases after the adopting of energy efficient technologies are a clear indication of the benefits of these technologies on energy savings.

Kusasalethu's electricity is mostly used for ventilation, refrigeration, hoisting and cooling. The (BU) savings were realized from the following initiatives; cooling auxiliary project, water supply optimization technologies and Eskom's DSM and the two water turbines. The DSM strategy monitors pumping systems and time them to make sure they consume less electricity during off peak periods, resulting in efficient use of Eskom's tariffs that rewards load-shifting. DSM also improved the efficiency of pumping operations. A Harmony respondent noted that without Eskom's funding, the water and air optimization projects would not have been possible. These areas are energy intensive in underground mining and

their intensity increases with increasing depth. To mitigate high electricity cost, senior personnel from the South African Chamber of Mines and Eskom recommend that mines should adopt the ventilation modeling software designed by Counsel for Scientific and Industrial Research (CSIR). A respondent from CSIR commented:

“The software helps with targeting ventilation where it is needed [and] when it is needed [ventilation on demand]. The other benefit of this software is that it maximizes ventilation in deep mining at lower cost [than], the current ventilation technology [which] cools the whole mine, all the time, which is not energy efficient” (Excerpt from telephone interview with a CSIR personnel, 2013).

Despite the savings realized by adopting clean technologies and methods, there are still a number of areas that need attention in order to realize additional savings. This research identified two areas. First, Kusasaletu needs to improve its underground technology particularly the means of energy supply to pumping systems Business day (2013) noted that hydraulic pumps are both water and energy inefficient as they often allow for water leakages between the pipes connecting the pump and the driller. The leakages result in 99% energy wastage. At the moment Kusasaletu is using hydraulic rock drilling technology, which both energy and water inefficient than electronic drills. A CSIR respondent supported the claim made by Business Day (2013) by identifying compressed air technology as being both highly energy and water intensive. The respondent argued stated:

“The old technology [hydraulic rock drillers] meant that machines such as pumps and other systems had to be manually adjusted. This meant that, if unattended, these machines would unnecessarily continue operating at high velocity, thus waste energy. These older technologies have however been replaced by energy efficient automated water pumps, air optimization and refrigeration which automatically regulate the amount of energy needed and the duration of pumping needed, thus saving energy”. (Excerpt from telephone interview with a CSIR respondent, 2013).

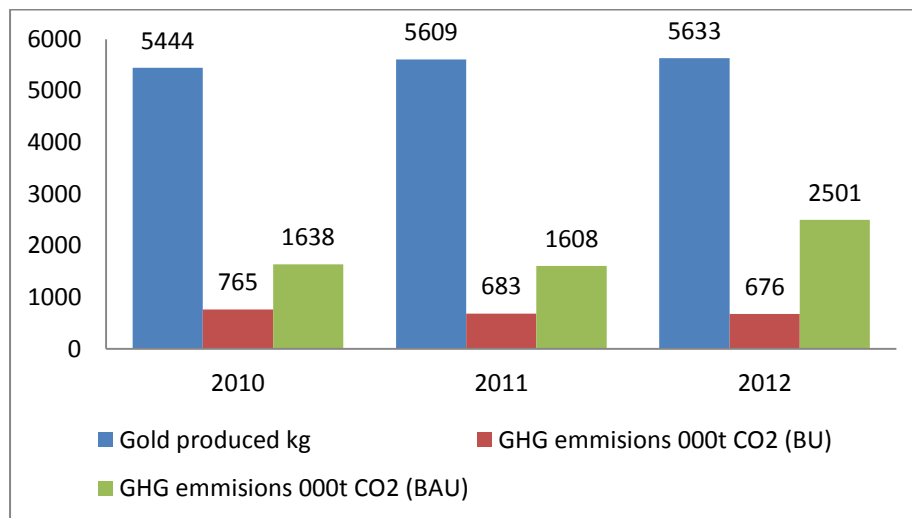
Other new developments in underground energy efficient technologies that Kusasaletu could adopt include the use of thermal scanning to detect potential ‘hot connections’ on electrical panels which protect relays and prevent power outages while monitoring the central systems for all pumps. Whilst Kusasaletu still has a lot of additional technologies to adopt to become ‘greener’ there is no denying the positive impact of the technologies adopted thus far on energy consumption. This impact also has a bearing on the GHG emissions, the focus of the next section.

4.4 GHG emissions and gold output

The decision to implement a carbon tax in 2015 has been cited as one of the major drivers for Kusasaletu to invest in clean technology. Projections are that a carbon tax is going to add to financial burdens for South African companies (South African National Treasury, 2013; Gibson, 2013; Steel and Engineering Industry Federation of South Africa, 2011; Thurlow, 2011 and, Onderdaal, 2011).

The link between gold output and electricity consumption has been identified and discussed. With regard to GHG emissions and electricity consumption, the South African Chamber of Mines, (2011), Eskom, (2013); and The National Climate Change Response White Paper, (2011), have all noted that Eskom primarily uses coal to generate electricity, coal is a major CO₂ emitter. This implies that South Africa’s electricity intensive industries indirectly contribute to GHG emissions. Figure 4.2 is a graphical comparison of GHG emission and gold output at Kusasaletu in the period 2010 to 2012. GHG emissions levels indicated in Figure 4.2 refer to scope 2 emissions, which make 99% of all emissions (CDP, 2013). Scope 2 emissions are made up of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Figure 4.2 compares the actual GHG emissions emitted over a period of three years and gold produced over the same period of time and further makes projections (BAU) on the GHG emissions had Kusasaletu not adopted energy efficient technologies.

Figure 4.2 Annual gold output and GHG emissions



Adapted from: Harmony, (2010, 2011 & 2012)

Figure 4.2 shows that under a BA regime, Kusasalethu decreased its scope 2 GHG emissions by 12 % from 765 000tCO₂e to 683 000tCO₂e between the years 2010 and 2011. In 2011/2012 financial year, the emissions declined further by 1% from 683000tCO₂e to 676000 CO₂e. The reductions were as a result of energy savings achieved after adopting energy efficient technologies as outlined in section 4.3.

GHG emissions under the BAU GHG emission projection between 2010 and 2011 stands at 1638 000t CO₂e and 1608 000tCO₂e each year respectively. This is a difference of 53% GHG reduction from the 2010 (BU) and 58% in 2011 (BU). The 2011/2012 BAU GHG emissions mirror the 2011/2012 BAU energy savings. The 2012 BAU projection indicates that Kusasalethu GHG emissions could have been 2501 000t CO₂e, 73% higher than the actual (BU) emission rate had the mine not adopted energy efficient technologies and methods in its operations.

The indirect reason for declining GHG emissions was Eskom's use of cleaner coal mining technology which improved coal quality and by implication reduced national Grid Emission Factor (GEF). Fecher (2011:1) defines GEF as "the total amount of GHG emitted per unit of electricity generated for and distributed by an electricity grid, taking into account imports of electricity from the interconnection with other grids". Harmony's respondent stated that;

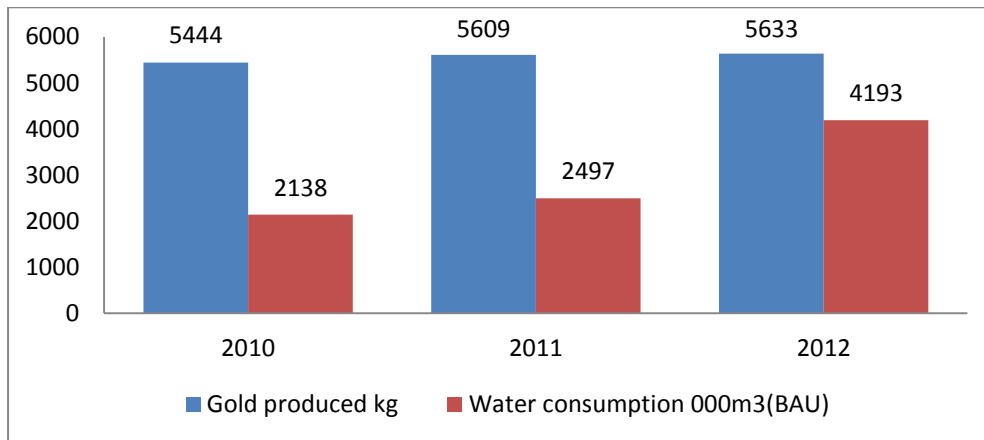
"Eskom has been improving its coal quality and the South African GEF has decreased, reducing the GHG emissions as a result"

This claim was supported by an Eskom's electrical engineer who stated that the cleaner the coal Eskom uses the lower the South African GEF becomes and lesser the GHG emissions are emitted. As proven by data presented above, the levels of GHG emissions are not only determined by the increase in energy consumption, but also depend on the coal mining technologies and methods used. The quality of coal has improved from 2010 to 2012, as a result of Eskom using the Underground Coal Gasification (UCG) technology since 2007. Cop17, (2011) defines UCG technology as an underground process of turning coal into gas. The UCG technology resulted in the South African GEF decreasing in ratio from 1.03 in 2010 to, 0.99 in 2011 and 2012. In light of increased electricity consumption and annual gold output as shown in Figure 4.1, GHG emissions would be expected to rise as projected by Harmony (2011), South African Chamber of Mines (2011) and the hypothesis made in chapter one, section 1.1. This has not been the case as seen in Figure 4.2.

4.5 Gold output and water consumption

The management of water has proven to be problematic in the last two years at Kusasalethu because of the unpredictable rain water flooding and the deeper excavation to access more ores. The evidence of this is the increasing of annual water consumption in the mine as shown in Figure 4.3.

Figure 4.3 Annual gold output and water consumption



Adapted from Harmony (2010, 2011 & 2012)

Figure 4.3 shows that between 2010 and 2012, annual gold output increased by 3%. This was as a result of increases in slime, rock, and ore mined. The 2010/2011, gold output resulted in 14% water increases from 2138000m³ to 2497 000m³. In 2011/2012 financial year, Kusasaletu's volume of milled ore rose by 9% and leading to 0.4 % increase in gold output. This increased water consumption by 40% from 2497 000m³ to 4193 000m³. The 2011/2012 increases in water consumption were also due to the hoisting of ore which increased the gold recovery rate by 8%. Water consumption also increased because in 2011/2012, 71% of production took place at levels below level 100 (new mine), 1% deeper compared to 2011. Although water demands cannot easily be reduced while trying to increase gold output by mining deeper and processing more ore, mitigation strategies have to be in place for predictable water problems such as rain water flooding.

Harmony's Sustainable Development Report (2010), states that the mine's return water dam catchment was filled with 60mm of rain water. This resulted in increased water seepage due to run-off and increased water levels in the dam. The seepage sump pump was unable to deal with increased water load; this caused approximately 3.9L/s or 0.34MI/day of seepage to overflow into the Loopspruit tributary. The pumping system had to be upgraded so that the

pipings facilities can be able to deliver seepage water to the return dam and secure efficient water usage from the main dam. The upgrading of pump and pipe systems together with the re-engineering of the chilled water systems have resulted in measurable water savings (Harmony, 2010). This problem led to the re-engineering of the main water systems and pumps. Harmony (2010) described the problem and intervention being taken:

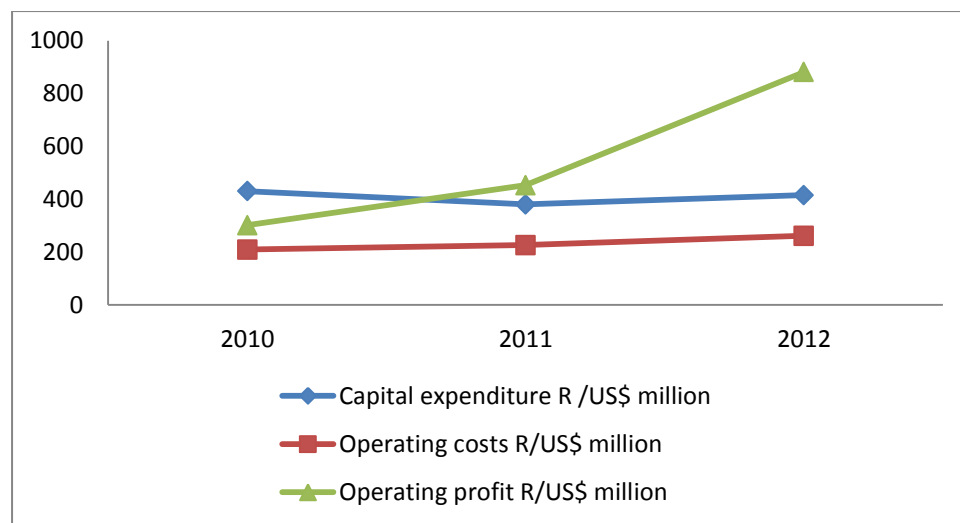
Re-engineering the closed loop chilled water system has allowed the project to make significant reductions in high-pressure piping. Having service water fed to the workings on each level from the discharge side of the air coolers, enabling surplus 'cool' water to be returned to the 98/100 level dam, resulted in fewer chilled water columns being needed for coolers that receive water feed. Cooling for the mine is supplied by two 3.5MW Bulk Air Coolers (BACs) located on 100 levels, which receive a water feed from three 3.5MW refrigeration plants installed on the same level. Air for the BACs was supplied by two Axial AFN Booster fans. A 22kV sub-station equipped with two 10MVA transformers, completed in early 2011 feeds the refrigeration complex in the operation. Developing the refrigeration chambers themselves proved challenging, since the work had to be done behind the existing mid-shaft loading arrangement on 100 levels; all the production from the original mine (above 100 levels) had to be subsequently hoisted. See Figure 1.2 for the different levels mentioned above (Harmony 2011).

To mitigate high water consumption, contingency plans had to be put in place for future eventualities that may include flooding. The rotational dam cleaning and re-engineering of the closed loop chilled water system has eliminated the risk of silting which has previously compromised the dam capacity and constrained pumping. In 2011, extra monitoring systems had to be installed on all large dams to monitor water levels and prevent mud from being drawn into the valves which cause production delays. In terms of deepening, the mine cannot avoid demands for more water as the refrigeration, cooling and hoisting systems will place further demands on water. The solution for water efficiency could be recycling of fresh water and minimizing leakages through better pumping systems.

4.6 Kusasaletu financial performance

Kusasaletu has made a multimillion Rand investment in energy efficient and cleaner operational technologies. The benefits associated with this investment are lower operational costs and improved operating profits as indicated in Figure 4.4.

Figure 4.4 Annual financial performance of Kusasaletu



Adapted from Harmony, (2010, 2011 & 2012)

Figure 4.4 shows that capital expenditure was at its highest in 2010 amounting to R430 million Rand. A reason for higher capital expenditure in 2010 can be attributed to the development and investment in the company's environmental strategy that included the appointment of new senior environmental executive. This cost R266 million, and maintenance of equipment cost R34 million. The 2011 capital expenditure dropped by 11% to R380 million due to reduced investment in new infrastructure compared to 2010. The 2012 capital expenditure was 415 million (US\$53 million), an increase of 8.4% from 2011. This increase was due to ongoing developments which included R52 million for equipment maintenance and R76 million for further deeper excavations and shaft maintenance. Kusasaletu's operational cost was also affected by external economic forces outside its control. In 2010 and 2011, the Rand/Dollar exchange which reached maximum of R7, 82 per

1 US\$ and a minimum of R6, 98/ 1US\$ increased operating costs by 9% from R208 864 per kg to R226 000 per kg. The 2011/2012 operating costs went up by 15 % from R226 million to R261 167 million/kg (US\$ 1046/Oz), this increase was largely due to increased electricity tariffs and annual labor cost increases. High energy demands as shown in Figure 4.1 have been identified as a major contributor to Kusasalethu's operational costs. Although operational costs increased slightly from 2010 to 2012, Kusasalethu has been managing these costs by mitigating energy costs. This mitigation partly resulted in higher operations profits.

The 2010 environmental strategy had a positive financial impact on the mine. Operating profits grew by 33% from R301 million in 2010 to R453 million in 2011. From the profits earned partly from efficient technologies and methods in 2010/2011, Kusasalethu invested in workers residential hostel hot water systems and cooling auxiliaries' technologies in 2012. This re-investment shows that gains made from clean technology investment can result in further re-investments in energy efficient technologies. This investment had a further positive impact on the 2012 operational profits. In 2011/2012, operating profits rose by 48 % from R453 million to R881 million (US\$114 million) partly due to higher average gold price favorable dollar-Rand exchange rate and increased annual gold output.

In 2011/2012 financial year, Kusasalethu also entered into a co-funded energy saving partnership with Eskom which resulted in three water and air optimization projects being approved. Kusasalethu contributed R20.1 million towards these projects. The effect of this investment is reflected in the 2012 increased capital expenditure which rose from R380 million to R415 million as reflected in Figure 4.4. The company's future plans are to invest R 560 million in capital expenditure on energy efficiency projects in all its mines, including additional investment in the Kusasalethu Mine. This is possible because of the realized benefits in the form of increased operating profits earned from previous investment.

Figure 4.4 shows that investment in clean technology can temporarily result in high capital expenditure noted by the South African National Treasury (2013) and Hillson (2000) in chapter two. The only cost that can continue to rise is the operating cost because it can be influenced by external factors outside the mine's control such as energy costs, nature of Rand/dollar exchange rate and labor costs. However, operating costs can be managed by implementation of energy efficient technologies and methods, efficient management of day to day activities and frequent maintenance of equipment and resources as suggested by Eskom (See Table 2.2). Harmony's commitment to further invest in clean and energy efficient projects is an indication that the previous investments produced positive results.

4.7. Cyanide management and development of cyanide alternatives

Harmony has not been publicly reported on its individual mine's cyanide consumption. However, the company reported an aggregated cyanide consumption of all its mines including Kusasalethu. Kusasalethu, Virginia plant and Kalgold all went through an external, independent compliance audit in 2009. Kusasalethu was certified as partially compliant in 2009 and was fully certified in 2011. The available data shows that in 2010 all the Harmony mines used 7884 tonnes of cyanide an increase of 25% from 2009's 6304 tonnes. Cyanide consumption increased in 2011 from 8332 tonnes to 11000 in 2012.

Cyanide technology has not changed much since its inception, however alternative technology development has been gaining momentum (See UNEP 2010). The problem with cyanide is not resident in its consumption but instead how it is managed in terms of handling and disposal. This is where being a signatory to the Cyanide Code of conduct places a mine as a safer user of cyanide. As long as Kusasalethu seeks to increase production, the mine will have to consume more cyanide for its gold recovery until alternative technology that is as effective as cyanide in gold recovery is found and commercialized.

From the data presented in this chapter, it is clear that the clean technology transition at Kusasalethu is mainly driven by legislative and economic pressures than environmental concerns. Clean methods preserve the mining environment; minimize operational cost and

increase profits. The mine can avoid costly environmental regulatory clamp downs that may shorten the mine's operational existence due to early closure.

The three main areas of technological development at Kusasalethu are: energy efficient technologies, efficient water management and cyanide usage and management. It is clear that energy contributes highly to GHG emissions and operational costs at Kusasalethu. Kusasalethu mine is the biggest energy consumer compared to all Harmony mines, thus more energy efficient technologies and methods need to be employed for sustainability of the mine. Water consumption has been on the increase from 2010 to 2012, especially between 2011 and 2012. Water consumption increased mainly due to three reasons firstly, increased hoisting of ore. Secondly, the 2011/2012, 1% deeper in excavations, the two activities led to the third reason which is an annual increase of gold output. In terms of cyanide management, Kusasalethu will need to manage its cyanide usage efficiently, especially that the mine is on a growth path.

Kusasalethu' 2010 operational overview state that in 2013 the mine plans to further increase its gold output as it will deepen its operations from level 109 up to level 113 (See figure 1.2) The mine estimated that its resource usage, mainly energy, water and cyanide will increase in the coming few years due to the company's growth projects whose objective is to increase production, (Harmony 2012). The company's focus is therefore to utilize those resources efficiently. Proper implementation of cleaner and energy efficient technologies and methods will minimize resource consumption, reduce operational costs and minimize environmental impact such as release of high levels of GHG emissions.

CHAPTER 5: SUMMARY OF FINDINGS, CONCLUSION AND SUGGESTIONS

5.1 Introduction

The purpose of this study was to explore the potential of clean technology at Harmony's Kusasalethu Gold Mine. This chapter summarizes the findings of the study in relation to the research questions and theory that underpinned the research. Finally the chapter draws conclusions and recommendations based on the findings of the research.

5.2 Research objectives: recap

This research was guided by two main research objectives; the first was to examine the possible impact of clean technology in the sustainability of South African gold mining sector. The second was to determine the opportunities and challenges associated with transition to clean technology in the gold mining sector as informed by the green economy principles in the context of sustainable development. The study focused on the global and South African gold mining industry with specific focus on Harmony's Kusasalethu gold mine. To meet these objectives, the research sought to answer the question: what challenges and opportunities will the transition to clean technologies pose on Kusasalethu? Kusasalethu was chosen as a case study for two main reasons. Firstly, for its unique mine designed to access the ore at deeper levels having depleted ores at higher levels. Due to this deepening project, the mine is faced with a challenge of having to minimize resource consumption (especially energy) so that it can remain sustainable.

5.3 Summary of main findings

The study revealed that 10% of Kusasaletu's operational cost is spent on energy. Underground ventilation, refrigeration and cooling consume most of the energy. Kusasaletu's 2010 to 2012 energy consumption trend under the BU regimes shows that energy consumption increased by 3% against an average of 2.5% increase in annual gold output. Increasing the annual gold output was a result of milling more ore extracted from deeper levels; however this posed energy intensive challenges. Whilst the exploitation of deeper ores explains the increases in energy consumption what is of interest to the study is the magnitude of the energy consumption. The BAU estimations show that the increases in energy consumption levels could have been as high as 65% in the absence of clean and energy efficient technologies. This reduction is attributed to the adoption of energy efficient underground technologies and methods. These technologies and methods included cooling auxiliary project, water supply optimization technologies and Eskom's DSM and the two water turbines.

However, the study disputed claims made in chapter one section 1.3 that high energy consumption automatically translates to high scope 2 GHG emissions. The study revealed that that the 2010/ 2012 BU 13% decline of GHG emission rates were mainly because of the value of GEF which determined the quality of coal. The decline in GHG emissions took place irrespective of 3 % energy consumption increase. The BAU estimations show that between 2010 and 2012, GHG emissions could have been up by an average of 78%, this figure would be accurate if GHG emissions were totally dependent on energy consumption. As such, the study found that the responsibility of reducing scope 2 GHG emissions mostly lay with Eskom's use of clean coal mining technologies. Noting Kusasaletu's measurable success in reducing energy consumption and mitigating high GHG emissions, water consumption and technology related to water efficiency has been lacking.

Water consumption has been on the increase from 2010 to 2012 at Kusasalethu. From 2010/2011 water consumption increased by 14% in 2011/2012 by 40%. The three major reasons behind these increases were (i) increased slime and milled ore, (ii) hoisting of waste with ore as a means of increasing gold recovery and (iii) the increased depth in mining. The technological deficiency (water pumping systems) resulted in failure of the main dam to capture and save rain water that flooded the shaft in 2010. To avoid the same problem, Kusasalethu started a process of re-engineering the closed loop chilled water system to mitigate water wastages. The new water system was designed to capture and re-use water which normally would have been wasted by pipe leakages.

The energy efficient technologies did not only reduce energy demands, but had a positive role in Kusasalethu's financial performance between 2010 and 2012. Kusasalethu's 2010 financial performance shows that acquisition of energy efficient technologies temporarily increased capital expenditure. This was expected and confirmed by Hilson (2000) and Chavalparit (2006). Operating costs increased steadily from 2010 to 2012. The operational cost increase was influenced by the Rand/dollar exchange rates, increased electricity tariffs and salary increases for the labor force. However, the operating profits eclipsed both capital expenditure and operational cost because of the mine's ability to improve gold output every year and because of savings achieved by energy efficient technologies. Energy efficient technologies and methods resulted in energy savings which in addition to minimizing operational costs, helped increase operational profits, thus proved to be a worthwhile investment.

From the operational profits earned between 2010 and 2012, partly because of clean technology investment and implementation, Kusasalethu committed R560 million for future re-investment in clean technology. This re-investment in clean technology confirms the assertion that successful implementation of energy efficient technology results in further investment in clean technology. Increase in cyanide consumption is a reflection of increased ore output and perhaps lack of alternative technologies to be used with cyanide or replace it completely.

5.4 Conclusions

The declining gold ores at higher surface in South Africa require that gold miners dig deeper to access ore reserves. This has implication on resource consumption, particularly energy and water. The eminent carbon tax will pose serious financial challenges for gold mines and the threats of climate change will pose environmental, social, economic and political challenges. However, this study has revealed that clean technology has a potential to reduce gold mine sector's carbon footprint, thus mitigate against climate change.

5.5 Suggestions

This study has revealed that the use of clean and energy efficient technologies can reduce energy consumption and scope two GHG emissions while reducing operational costs and improving operational profits. However, the gold mining sector is not the direct major emitter of GHG emissions. Coal mines and their coal mining methods are predisposed to be the higher emitters. The study has also shown that the use of clean technology in the coal mining process result in “cleaner” coal that eventually mean lower scope 2 GHG emissions. As such, further research is required to:

- Explore coal mining technology with the aim of finding ways to reduce GHG emissions.
- Investigate the energy mix options that will minimize the use of coal and encourage renewable energy sources to eventually dominate energy production.
- Research on developing climate change adaptation strategies in the coal mining sector.

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LIST OF APPENDICES

Appendix A: Application to conduct a study at Harmony Gold' mines



Harmony Gold Mining Company
Environmental Management Division
P.O. Box 2, Randfontein 1760
Randfontein Office park
Corner of Main Reef Road and Ward Avenue
Randfontein

Dear Sir/Madam

**RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH (STUDENT BONGANI CHAVALALA
– REGISTRATION NO. 146513078)**

This letter seeks to confirm that Mr. Bongani Chavalala (Student number 146513078) is a registered student with the University of South Africa under my supervision. Mr Chavalala is registered for the degree of Masters of Science in Environmental Management. Mr. Chavalala's research addresses critical aspects in the field of green economy and growth, with special emphasis on the mining sector focusing on Harmony Gold Mining Company as a case study. To the best of my knowledge, this is a groundbreaking piece of work that will assist not only your company but the entire industry in engaging with the new phenomenon. Details regarding the research project are presented in the next paragraphs.

The research topic:

Assessing green economy transition potential in South Africa's mining sector: Case of Harmony Gold Mining Company.

Envisaged outcomes of the research:

This research will contribute to the existing knowledge in terms of risks and opportunities associated with transition to a green economy in South Africa's mining sector. The recently concluded Green Economy Accord for South Africa will provide a conceptual framework for analysing the situation. The study will therefore assist the mining sector, government, labour and other key stakeholders to understand each other and address the challenges whilst harnessing the opportunities brought by transition towards a green economy. Since the research will unpack the scientific reasoning that brought the green economy to the attention of government and environmental organisations alike, the outcomes will bring understanding to the mining sector concerning the government position on the socio-economic and environmental concerns in the country. The research will also enlighten environmentalists and the government on the challenges faced by business in transition to the green economy in the context of sustainable development and poverty eradication.

Type of assistance required:

The following represents the nature of assistance the student needs: Permission to conduct research in the mine premises (bearing in mind the conditions that the mine management will spell out); Permission to interview relevant mine employees in confidence and without violating their privacy and other ethics related issues; and Provision of documents which are related to the research topic, (internal and public documents) as the company deems appropriate.


Should you need further information regarding this matter, please do not hesitate contacting me on email: nhamog@unisa.ac.za; Land: 012-433-4725 or Cell: 0731631114. I look forward to receive your positive response. Thank you.

Regards,

Professor Godwell Nhamo

Supervisor

Appendix B: Permission letter to conduct a Study at Harmony Gold mine



HARMONY GOLD MINING COMPANY LIMITED
Randfontein Office Park
Cnr Main Reef Road and Ward
Avenue, Randfontein, 1759

P O Box 2, Randfontein, 1760
Johannesburg, South Africa

T +27 11 411 2000
F +27 11 692 3879
W www.harmony.co.za

NYSE trading symbol HMY
JSE trading symbol HAR

Dear, Mr. Bongani Chavalala

Student Number: 46513078

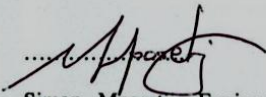
RE: CLEARENCE LETTER TO DO A MASTERS STUDIES: CLEAN TECHNOLOGY TRANSITION POTENTIAL IN SOUTH AFRICA'S MINING SECTOR: CASE OF HARMONY GOLD MINING COMPANY.

I acknowledge receipt of your request to conduct research using Harmony Gold Mining Company as a case study for the above mentioned research topic: as stated on the request letter dated 10 August 2012. As agreed, the granting of this permission means that Harmony will assist you with the following:

- Permission to conduct research in the mine premises (bearing in mind the conditions that the mine management will spell out).
- Permission to interview relevant mine employees in confidence and without violating their privacy and other ethics related issues.
- Provision of documents which are related to the research topic, (public documents) as the company deems appropriate.

This assistance will be provided within the terms of the confidentiality and disclosure agreement you have signed.

Regards,



Simon Mporetji, Environmental Manager: Group Systems Harmony Gold Mining Co Ltd
Tel: 011 411 2062, Cell: 0793102358, Fax: 011 6969655, Simon.Mporetji@Harmony.co.za Website: www.harmony.co.za

Directors: PT Motsepe* (Chairman), MJ Motoba* (Deputy Chairman), GP Briggs (Chief Executive), F Abbott (Financial Director), HE Mashego (Executive Director), JA Chissano*, FFT De Buck*, KV Dicks*, Dr DS Lushaba*, CE Markus*, M Maimang*, J Wetton*, AJ Wilkens*
*Non-Executive; *Mozambican

Secretary: Riana Blaschhoff

Registration Number: 1950/038232/06

Appendix C: Research ethics clearance letter

 UNISA university of south africa	
2013-05-29	
Ref. Nr.: 2013/CAES/101	
To: Student: B Chavalala Supervisor: Prof G Nhamo Department of Environmental Science College of Agriculture and Environmental Sciences	Student nr: 46513078
 Dear Prof Nhamo and Mr Chavalala	
Request for Ethical approval for the following research project:	
<i>Clean technology transition potential in South Africa's gold mining sector: Case of Harmony's Kusasalethu mine</i>	
 The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. Ethics clearance for the above mentioned project (Ref. Nr.: 2013/CAES/101) is approved after careful consideration of all documentation submitted to the CAES Ethics committee.	
 The researcher is requested to uphold the confidentiality agreement signed with the Harmony mine at all times.	
 Please be advised that the committee needs to be informed should any part of the research methodology as outlined in the Ethics application (Ref. Nr.: 2013/CAES/101), change in any way. In this instance a memo should be submitted to the Ethics Committee in which the changes are identified and fully explained.	
 Kind regards,	
	
 Prof E Kempen, CAES Ethics Review Committee Chair	
  University of South Africa Preller Street, Muckleneuk Ridge, City of Tshwane PO Box 392 UNISA 0003 South Africa Telephone: +27 12 429 3111 Facsimile: +27 429 12 429 4150 www.unisa.ac.za	

Appendix D. Questionnaire for Harmony

QUESTIONNAIRES

Please respond to this questionnaire by ticking (✓) inside the box next to the appropriate answer, or rank and/ or complete the space provided.

RESEARCH TOPIC: CLEAN TECHNOLOGY TRANSITION POTENTIAL IN SOUTH AFRICA'S GOLD MINING SECTOR: CASE OF HARMONY'S KUSASALETHU MINE

Bongani Chavalala.

Student number: 46513078

Respondent biographical data

Age: up to 19 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ > 60 ☐

Sex:

Years of experience at Kusasalethu:

Section A: Clean technology assessment

1. Kusasalethu is employing the conventional mining method to access the deeper part of the Ventersdorp Contact Reef. What are the implications of this operation in terms of **energy demands from the following energy sources**? Please tick (✓).

	Diesel	Electricity	Gas	Petrol	Others		
Higher							
Lower							
Same							

2. Which **technologies** have you been using in Kusasalethu before you invested in the new ones? Please be specify.

3. Please list the old and **new technologies/methods** used under each **mining process** stated bellow.

Technology per process and method(s)	Old	New
Ore exploration		
Method		
Access to ore body		
Method		
Blasting		
Method		
Transportation/hauling		
Method		
Processing		
Method		
Refining		
Method		

4. In your view, what were the **drivers** for investing in the new technology? Please rank by placing a numerical figure from 1-5 against each driver. Please feel free to add other drivers in the space provided and rank together with those provided.

Environmental concerns		High operational costs		Shareholder demands		Government legislation. E.g. carbon taxes		Maintaining reputation	
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Any other, Please state bellow and include in ranking.

5. In your view, what have been the **challenges**, if any that you faced when you needed to implement the new technology? Please rank by placing a numerical figure from 1-5 against each driver. Please feel free to add other drivers in the space provided and rank together with those provided.

Structural barriers		Government legislation		Technological costs		Acceptance by management		Acceptance by workers		Technical capacity (worker skills)	
---------------------	--	------------------------	--	---------------------	--	--------------------------	--	-----------------------	--	------------------------------------	--

Any other, please state bellow and include in ranking.

6. What was the **average electricity consumption** per ounce of gold milled on the previous compared to the new technology? Please tick (✓) and state **electricity consumption difference**.

Same		
Lower		

Higher		
--------	--	--

7. Taking into consideration Eskom's increased electricity hikes, how has this **affected the average energy consumption** rate per ounce of gold milled in the current technology? Please tick (✓).

	Diesel	Electricity	Gas	Petrol	Others		
Increased							
Declined							
Same							

8. All your South African mines, including Kusasalethu have a 25 year life span. What effect can new technology do for the **life expectancy and profitability of a gold mine**? Please tick (✓).

	Life expectancy	Profitability
Decrease		
No effect		
Increased		

9. Please tick (✓) where you are implementing clean technology and methods on the following gold value chain (If at all, please indicate as such).

	Technology	Methods
Mining		
Fabrication		

Refining		
Recycling		
Mine closure		

10. What technology and methods are you using on each of the gold value chain stages?

Please specify.

Value chain:	Mining	Fabrication	Refining	Recycling	Closure
Technology:					
Methods:					

Section B: Greenhouse gas emissions assessment

11. What are the implications of increased energy demands with regard to **greenhouse gas emissions (GHG)**?

12. What was the **direct GHG emission ratio per annum** on the **previous technology** compared to the new technology on this shaft? Please tick (✓) and state ratio difference.

Lower		
Same		
Higher		

13. What was the indirect **GHG emission ratio per annum** on the **previous technology** compared with the new technology? Please tick (✓) and state the ratio difference.

Lower		
Same		
Higher		

14. What is the direct **GHG emission ratio per annum** on the **new technology** compared with the old technology? Please tick (✓) and state the ratio difference.

Lower		
Same		
Higher		

15. What is the **indirect GHG emission** ratio per annum on the **new technology** compared to older technology? Please tick (✓) and state the ratio difference.

Lower		
Same		
Higher		

Section C: Finance performance assessment

16. What are the **financial implications** of **increased energy demands** of the mines operation? Please tick (✓).

None	
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Low	
High	

17. From the day you started operating with the **new technology**, can you say operational costs have: please tick (✓).

Declined	
Increased	
Same	

18. Are there **other factors**, besides the **new technology that may have an effect** on operational costs? If any, please specify.

19. From the day you started operating on **new technology**, can you say that **monthly profits** have: please tick (✓).

Declined	
Increased	
Remained the Same	

20. Are there **other factors** that may have affected **reported annual profits** besides the new technology? If any, please specify.

Have you started seeing a **financial return** on investment you made with the **new technology**? Please tick (✓).

Yes		
No		

21. If yes **specify the percentage of profits**, if no, by **when** do you think you will start to see a return on investment?

22. What is the reason for Eskom to provide **financial funding** for the water turbines and the three air optimization projects in Kusasalethu mine?

According to FY 11/12 report, your decision to replace energy intensive operations and technologies is a strategy to avoid exposure to **high carbon tax**.

23. How much impact can carbon tax have on **Kusasalethu's profitability**? Please tick (✓).

No impact	
Low impact	
High Impact	

24. How much of your decision to implement new technology is influenced by the possibility of **high carbon tax**?

No influence	
Low influence	

High influence	
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25. Have you **re-invested** the profits you made from the energy savings made by clean technology? Please tick (✓).

No	
Yes	
Not yet	

26. If the answer is “**no**”, please state the reason why. If the answer is “**maybe**”, please state by when you plan to.

Section D: Regulations

27. How much effect did **government legislation** on green economy (including climate change and sustainable development have on your decision to invest in clean technology? Please tick (✓).

No effect	
Low effect	
High effect	

28. Does the South African trade and mining policy allow the gold mining sector to implement clean technology? Please tick (✓).

Yes	
-----	--

No	
----	--

If “no”, Please substantiate you’re your answer.

29. In FY 11/12, you mention that there are debates about the energy **feed-in tariff guidelines** proposed by National energy regulator of South Africa (NERSA). What were the **concerns raised in these debates**?

30. How much role does the **carbon disclosure project** (CDP) play with you meeting your carbon footprint targets?

No role	
Lower role	
High role	

In FY 11/12, you state that Harmony is not conceptually opposed to the state using **financial incentives** to assist the mining industry to reduce emissions; however you are concerned about the potential impact that this will have on the **industry’s competitiveness**:

31. How much role does the **JSE SRI** play in your meeting your carbon footprint targets?

No role	
Lower role	
High role	

32. How **important** are **state financial incentives** for South African gold mines to implement clean technology? Please tick (✓).

Not important	
Important	
Very important	

33. How important is a clean technology in a gold **mines' competitiveness**? Please tick (✓).

Not important	
Important	
Very important	

34. Please state comments, views, opinions and suggestions about the challenges and opportunities of adoption of clean and energy saving technologies in South African gold mines, specifically at Kusasalethu.

Thank You for your cooperation!

Appendix E. Interview guide for mining stakeholders

Eskom, CSIR, South African Chamber of Mines, South African Council for Geosciences

Please note that these questions are part of data collection method for my Msc studies. Your input will be used for this purpose only. Please feel free to skip questions you do not have answers for. You may elaborate as much as you can; these are more of discussion questions than requests for specific answers. I may send you follow up questions later or propose a telephonic conversation if I need further clarity.

1. What is the role of your organization in relation to South African Gold mining sector and clean technology innovation?
2. According to the organization what is the status of South African Gold mining sector in the adaptation of clean and energy efficient technologies and methods?
3. What are the major environmental concerns raised by gold mining processes?
4. What are the major areas of technological development in South African gold mining?
5. What steps and recommendations does your organization have for the South African gold mining sector if it is to achieve cleaner, and energy efficient mining?
7. What are the challenges or difficulties that the South African gold mining sector has in adopting clean and energy efficient technologies?
8. What would be the major benefits that can be achieved by South African gold mining sector if it transitioned to cleaner and energy efficient technologies and methods?
9. Can you please list any old “dirty technologies” that should be replaced by clean, energy efficient technologies?

Please feel free to call me or email me for any clarity on these questions.

Bongani Chavalala

0786719232

012 433 4638

Thank you for your input!